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DEPARTMENT OF REGISTRATION AND EDUCATION

Deep-Water Sediments Adjacent to the Borden Siltstone (Mississippian) Delta in Southern Illinois

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DEEP-WATER SEDIMENTS ADJACENT TO THE BORDEN SILTSTONE (MISSISSIPPIAN) DELTA IN SOUTHERN ILLINOIS

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ABSTRACT

Rocks of early Valmeyeran age (Mississippian) exhibit four major, laterally adjacent, noncontemporaneous, nonintergrading lithologic aspects in southern Illinois. The Fern Glen Formation, Burlington Limestone, and Keokuk Limestone represent a crinoidal carbonate bank that stood west of and topographically above a deep-water basin. The Borden Siltstone, Warsaw Shale, and Springville Shale represent parts of a delta that invaded and restricted the deep-water basin and overrode the crinoidal bank. The Fort Payne Formation is a tongue-shaped body of dark-colored, cherty, impure limestone that partially filled the deep-water basin after the end of deltaic deposition. The Ullin Limestone is a new name proposed for the light-colored bryozoan-rich limestone that overlies the Borden and Fort Payne and filled topographic depressions left after Fort Payne deposition ceased. The Salem Limestone is a shallow-water carbonate that overlies the lower Valmeyeran sequence.

The four major lithologic units are bounded by depositional surfaces that commonly have primary dip. The boundaries are between contrasting lithologies and without intertonguing or transitional zones. Bedding in the lower Valmeyeran rocks, traced between closely spaced wells by means of electric logs, does not cross dipping lithologic boundaries.

INTRODUCTION

Four major lithologic units of variable thickness, consisting of eight formations, occupy the stratigraphic interval of early Valmeyeran age (Middle Mississippian) below the Salem Limestone in southern Illinois (figs. 1, 2). The first

Figure 1 - Dominant early Valmeyeran rock types. Lines of cross sections A-A' (fig. 10), B-B' (fig. 11), and C-C' (fig. 15).

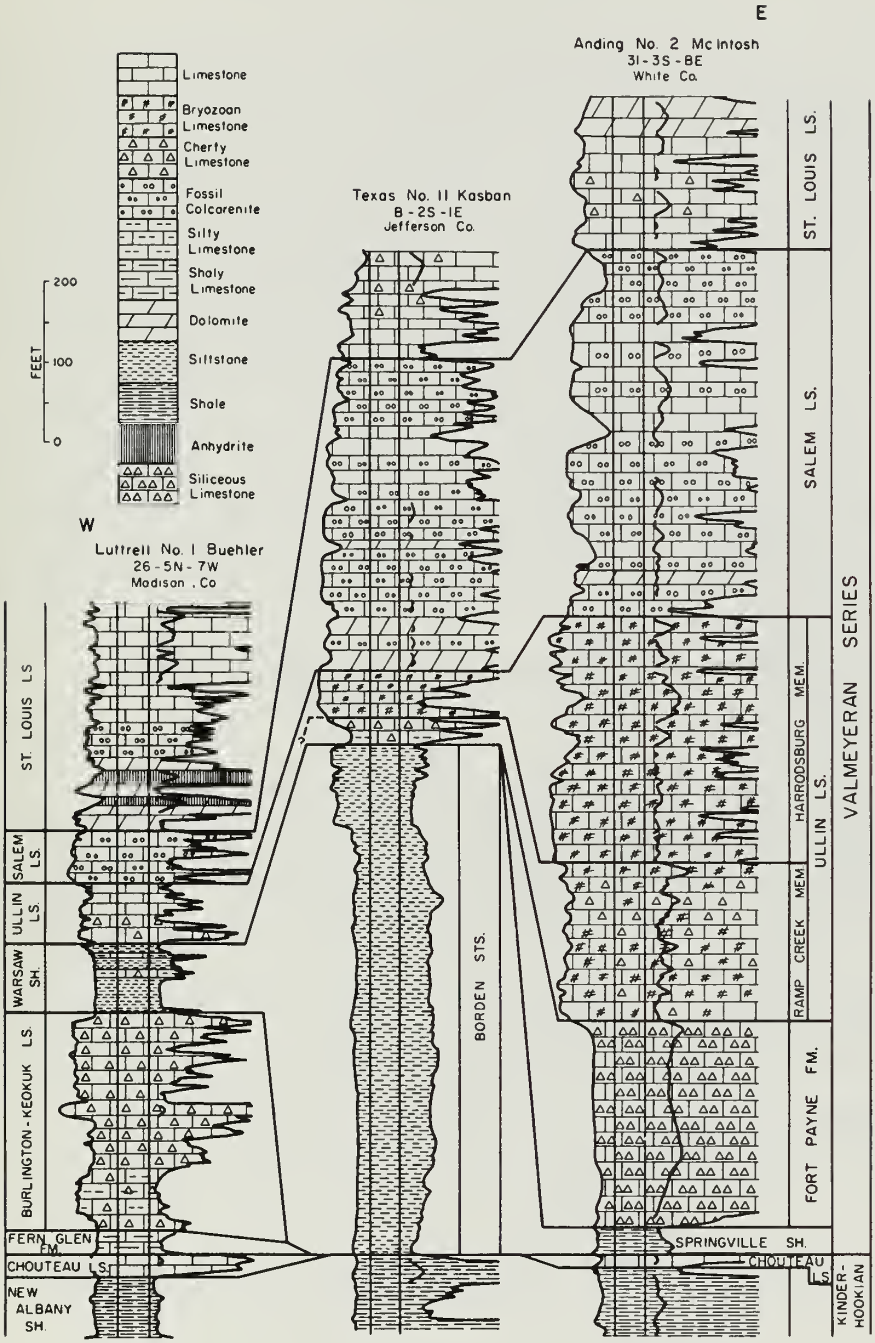


Figure 2 - Electric and lithologic logs showing the four major lower Valmeyeran units and stratigraphic nomenclature.

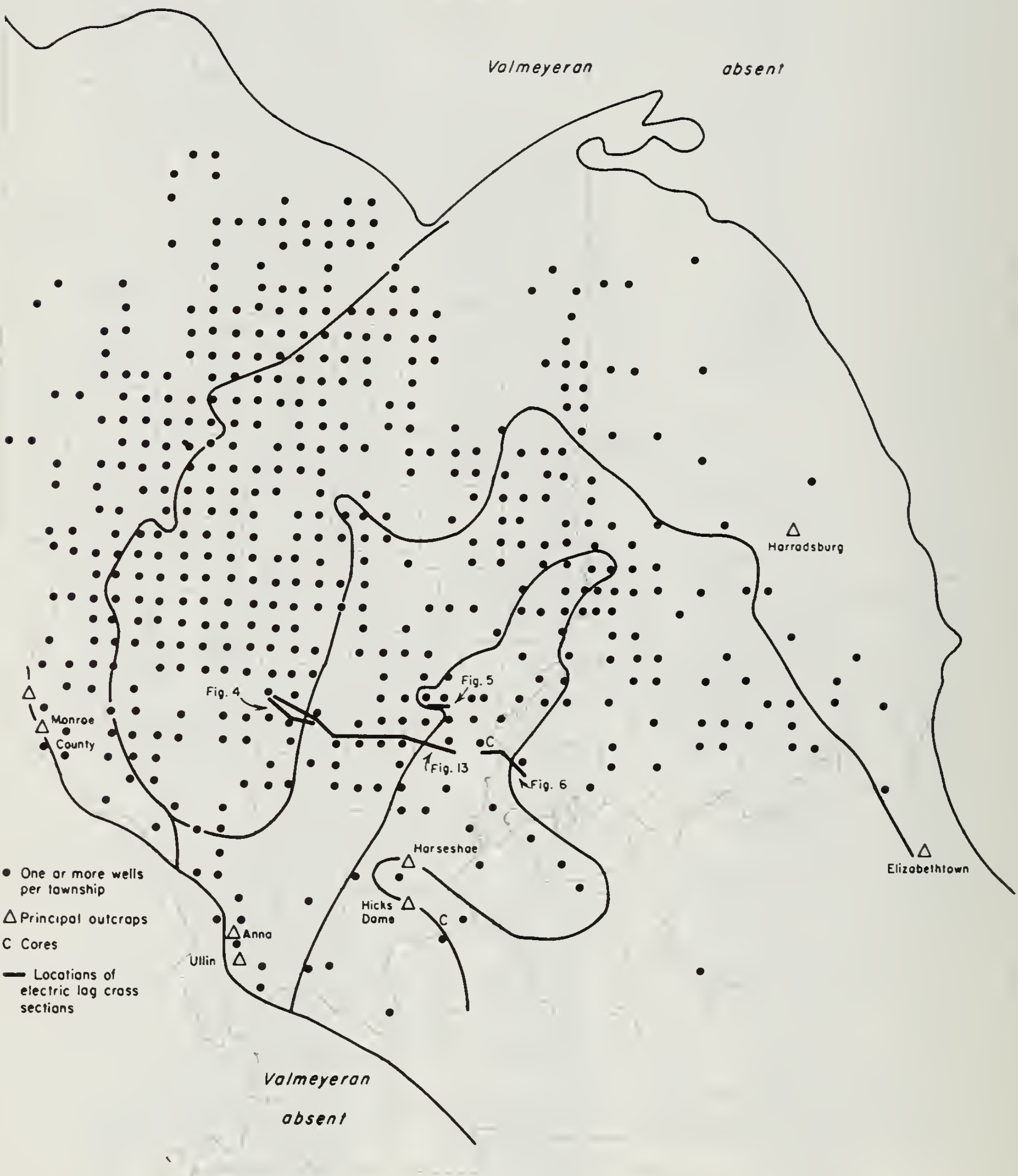


Figure 3 - Subsurface and surface control.

major unit consists of the Fern Glen Formation, Burlington Limestone, and Keokuk Limestone. These formations are dominantly light-colored, cherty, crinoidal limestone and lie at the base of the Valmeyeran in western Illinois (figs. 1, 2). The second major unit is the Borden Siltstone delta that lies in central Illinois east of the Burlington and Keokuk Limestones. The Warsaw Shale, which overlies the Burlington and Keokuk sequence in western Illinois, and the Springville Shale, which is the basal Valmeyeran unit in southeastern Illinois, are extensions of the delta. The third major unit, dark-colored siliceous limestone of the Fort Payne Formation, overlies the clastic sequence in southeastern Illinois. The fourth unit is light-colored bryozoan-rich limestone, herein named the Ullin Limestone. It overlies the Fort Payne in southeastern Illinois and overlaps the Fort Payne westward to lie on the Borden and Warsaw (figs. 1, 2).

This study delineates the general stratigraphic relationships of the various pre-Salem Valmeyeran units in southern Illinois. Electric logs from approximately 400 wells in Illinois, Indiana, and western Kentucky were examined (fig. 3), and lithologic cross sections were constructed from sample studies of more than 100 wells. Chemical analyses of the Fort Payne Formation and thin section studies of selected units were made to determine lithologic types. Sample strips from 50 wells drilled in southwestern Indiana, on file at the Indiana Geological Survey, were examined.

STRATIGRAPHIC RELATIONSHIPS

Previous Work

The stratigraphic relationships within the lower Valmeyeran have been uncertain because of lack of extensive surface outcrops in critical areas and the absence of a detailed subsurface study in Illinois. Previous workers, in general, have thought that the dominantly limestone Burlington-Keokuk section graded laterally eastward across the Illinois Basin into the dominantly clastic lower Valmeyeran Borden Group in southern Indiana (Stockdale, 1939; Payne, 1940; Weller and Sutton, 1940; Pinsak, 1957).

This study shows that the four major lower Valmeyeran lithologic units present in the Illinois Basin do not grade into each other. They overlie one another along depositional surfaces that sometimes dip with respect to lower and higher units. Some of the units pinch out and are overlapped by others. No more than three of the four major units are recognizable at any one spot in Illinois, and in places only one may occupy the stratigraphic interval. The four units are not contemporaneous where they are laterally adjacent in southern Illinois, but this does not preclude contemporaneous deposition of some of these units in other areas.

Evidence that the major units do not grade laterally into each other comes from combined electric log and sample studies and from outcrop information.

Stratigraphic Boundaries

Sample studies show that boundaries between the four major units are usually marked by sharp lithologic breaks. In places, the lithologic boundaries dip with respect to adjacent units. There are no transitional zones and no intertonguing along dipping lithologic contacts. Since there is no evidence of intergradation, the dips are considered primary depositional dips.

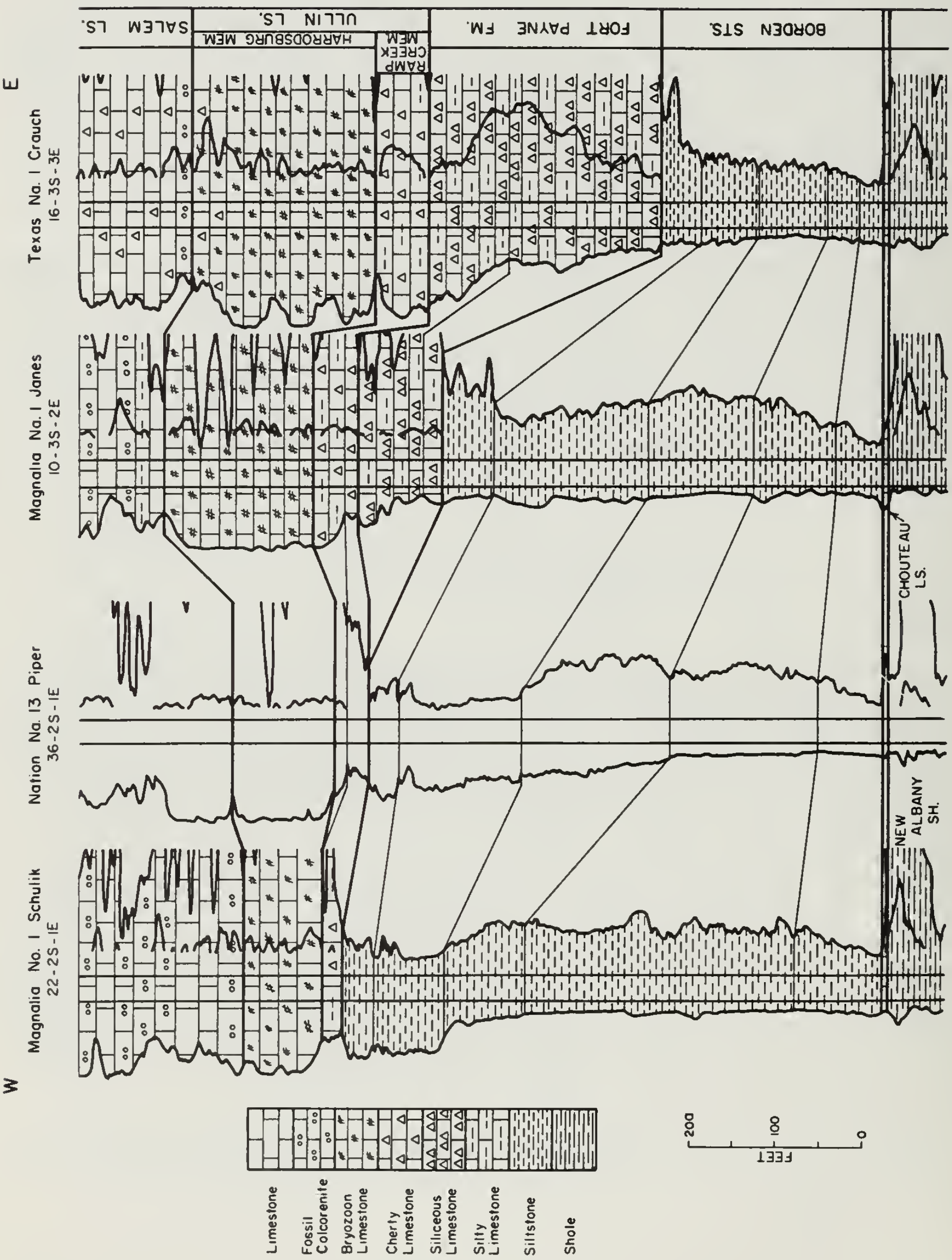


Figure 4 - Cross section showing east dip of inclined bedding in the foreset slope of the Borden delta and in the overlying Fort Payne Formation in Jefferson County, Illinois (fig. 3).

Bedding can be traced by correlating electric logs from closely spaced wells. Bedding planes in the lower Valmeyeran also exhibit primary dip with respect to the base of the Valmeyeran (figs. 4, 5, 6). Bedding does not cross from one lithologic unit to another; rather, contemporaneous bedding surfaces, in general, lie parallel to the dipping lithologic boundaries. The parallelism of bedding planes and lithologic contacts indicates that the lithologic units do not intergrade or intertongue along their dipping boundaries and that they are not contemporaneous.

Depositional dips of 200 feet per mile have been recorded for individual beds in the Borden Siltstone, which has the steepest average primary dips (fig. 7). Limestone units usually show lesser dips.

An electrical resistivity map of the lower 500 feet of Valmeyeran rocks in a portion of southeastern Illinois clearly reflects the presence of three of the major lithologic units (fig. 8). The Borden Siltstone characteristically has very low resistivity, and the overlying Fort Payne Formation has very high resistivity (figs. 2, 8). The Ullin Limestone and the Fern Glen, Burlington, and Keokuk succession have an intermediate resistivity.

The Delta Foreset Slope

The case for nongradation is strengthened by the presence of a major delta tongue in the Illinois Basin during early Valmeyeran time (Swann, Lineback, and Frund, 1965). The Borden delta sediments overlie the Burlington and Keokuk Limestones, along a dipping depositional surface. Individual beds can be traced from the topset portion of the delta down through the foreset portion to the bottomset beds, a vertical distance of 600 feet in places. Along the southeast side of the delta tongue in southern Illinois, the foreset slope of the delta rose at least 600 feet above the floor of the basin at the end of deltaic deposition in that area. The siliceous or calcareous sediment that was deposited on the foreset slope after cessation of deltaic deposition could not intergrade with or intertongue with the preexisting deltaic sediments that formed the laterally adjacent foreset slope. The overlying sediments preserve the shape of the last-formed foreset slope of the delta. Similar topographic situations existed during deposition of other lower Valmeyeran units in southern Illinois and in Indiana.

Outcrops of lower Valmeyeran rocks, other than the Fern Glen, Burlington, and Keokuk Formations along the Mississippi River, are extremely limited in Illinois. In Indiana, the thick clastic sediments of the Borden Group dominate the interval and the outcrop belt follows the depositional strike. However, light-colored carbonates near Elizabethtown, Kentucky (fig. 3), overlie the surface of a westward-thinning body of siltstone that probably was deposited in a delta situation analogous to that in central Illinois. Here, also, carbonates do not intergrade with the siltstone, but overlie it along a dipping depositional surface.

UNDERLYING ROCKS

The Valmeyeran rocks in Illinois lie on the Chouteau Limestone (Kinderhookian), but overlap it in some areas to lie on the New Albany Shale Group and older rocks. The Chouteau is overlain by the Fern Glen Formation, Burlington Limestone, Borden Siltstone, Springville Shale, Fort Payne Formation, and Ullin Limestone in different parts of Illinois. The base of the Valmeyeran is used as a

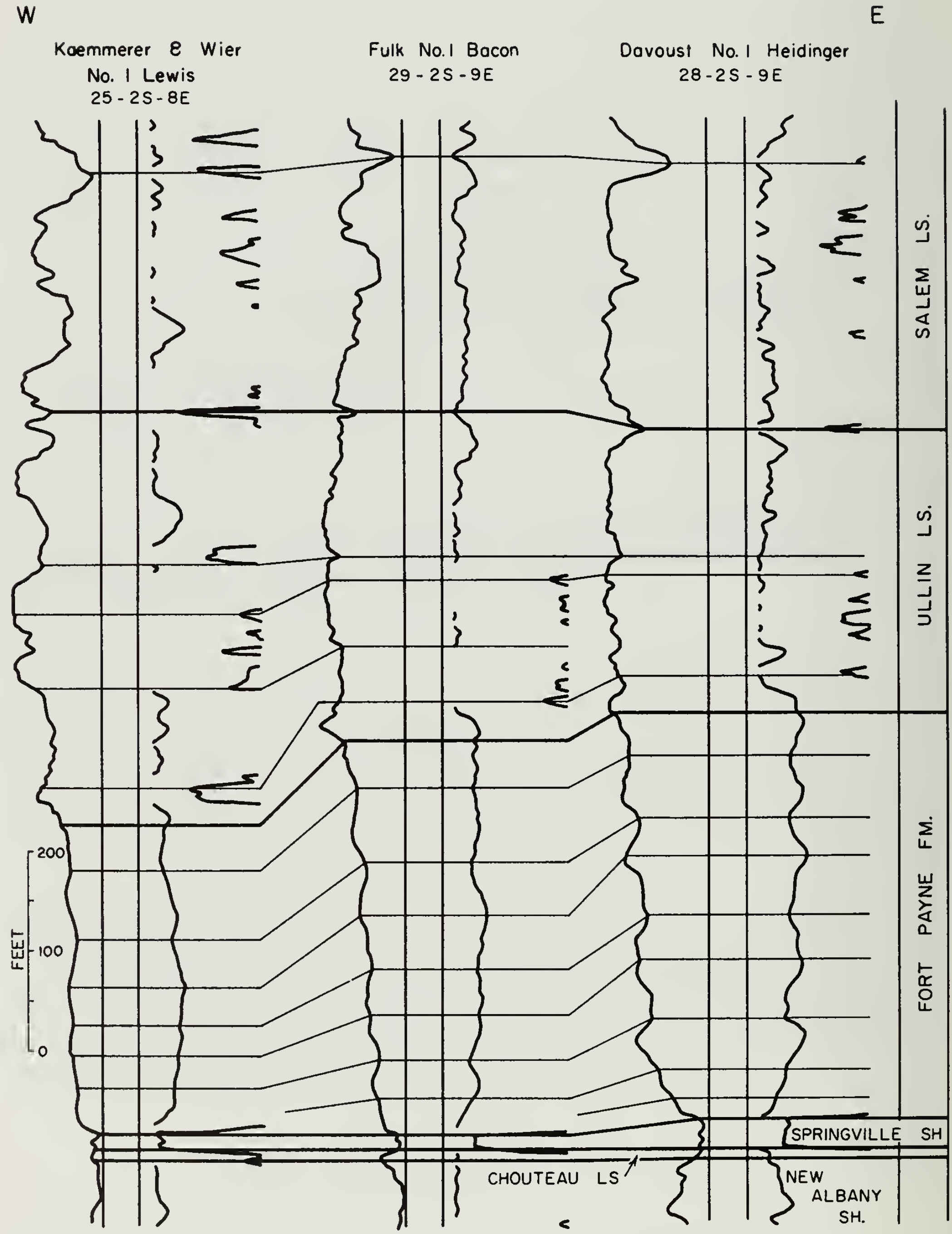


Figure 5 - Cross section showing west dip of inclined bedding in the Fort Payne Formation and Ullin Limestone on the west side of the Fort Payne tongue in Wayne County, Illinois (fig. 3).

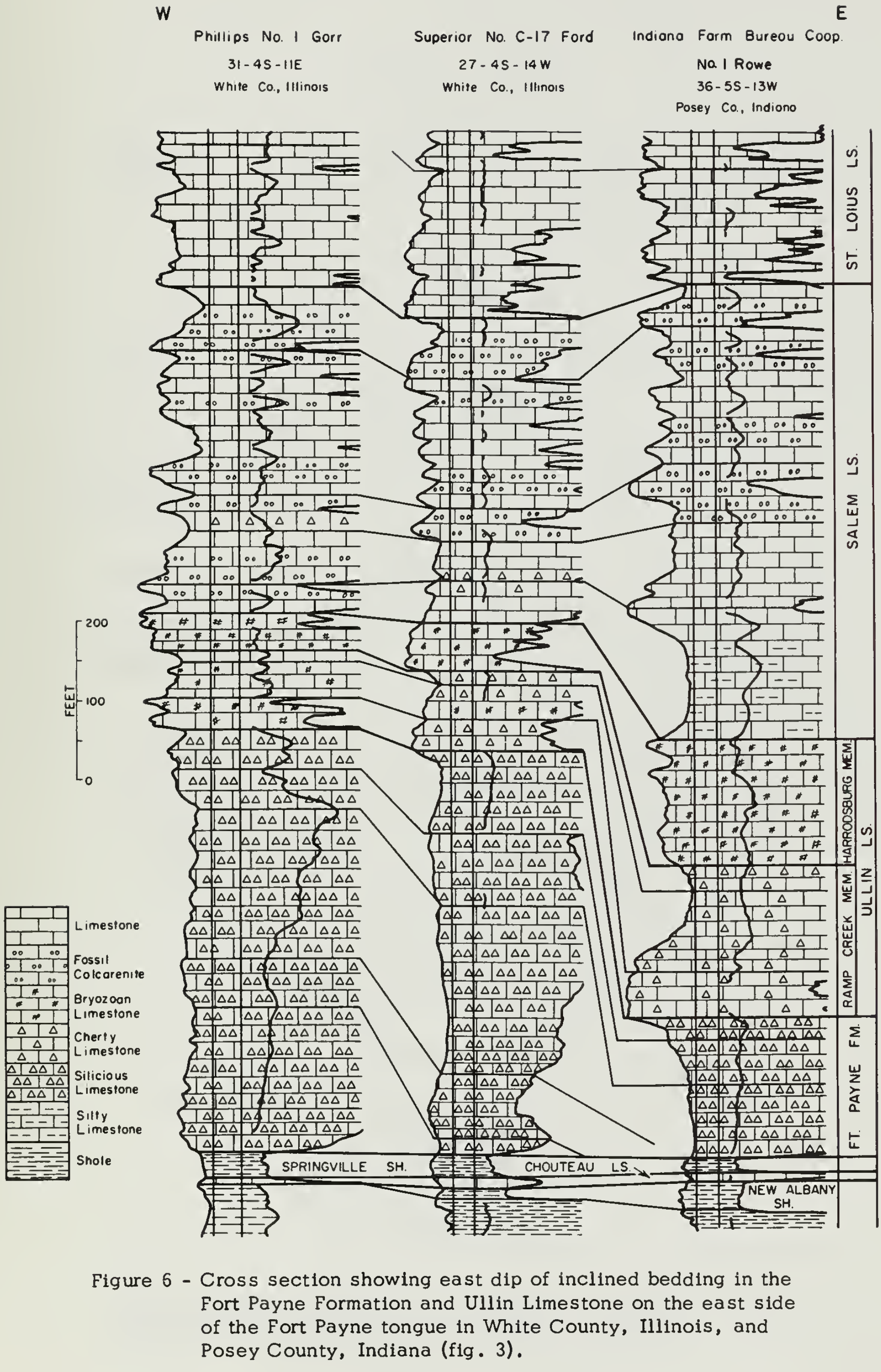


Figure 6 - Cross section showing east dip of inclined bedding in the Fort Payne Formation and Ullin Limestone on the east side of the Fort Payne tongue in White County, Illinois, and Posey County, Indiana (fig. 3).

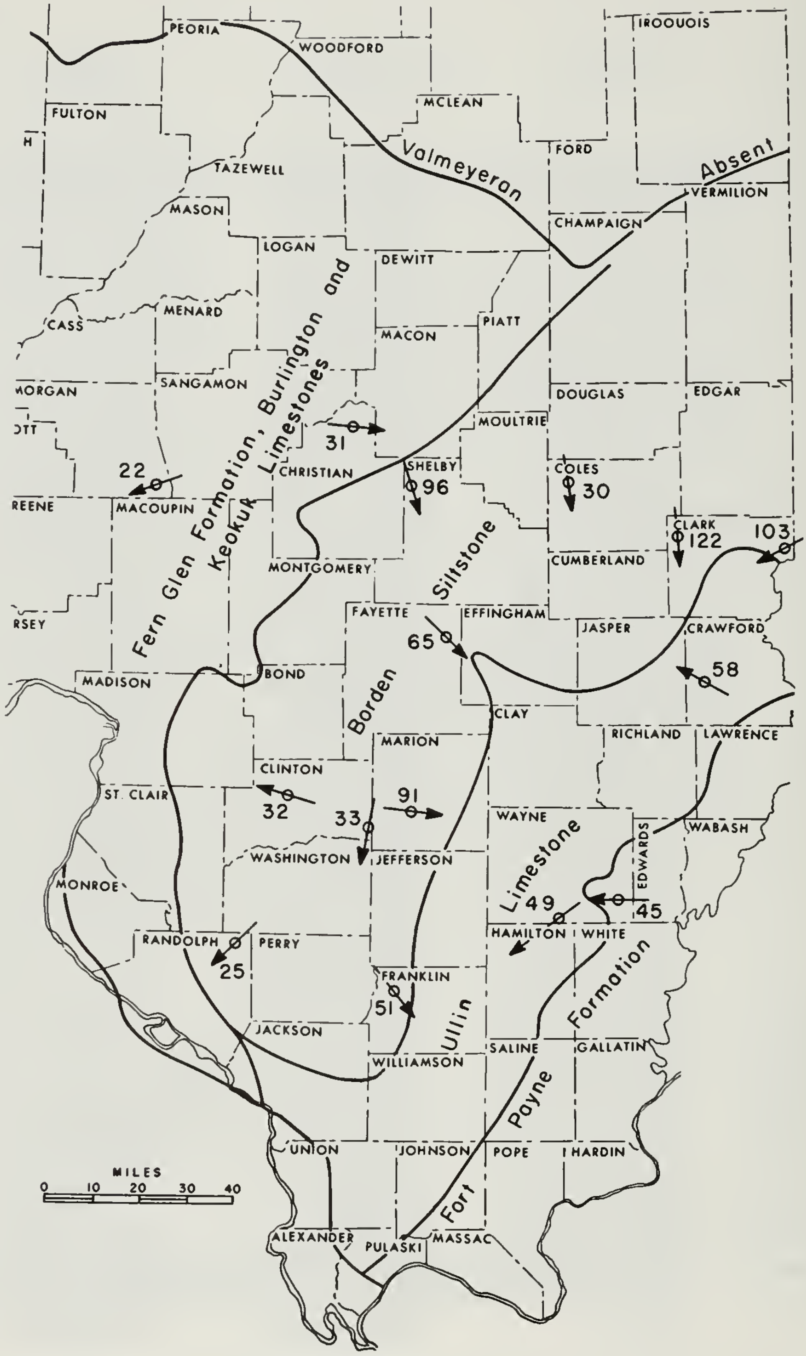


Figure 7 - Direction and average depositional dip, in feet per mile, of lower Valmeyeran strata. Each dip is computed from electric logs from wells within one mile of each other.

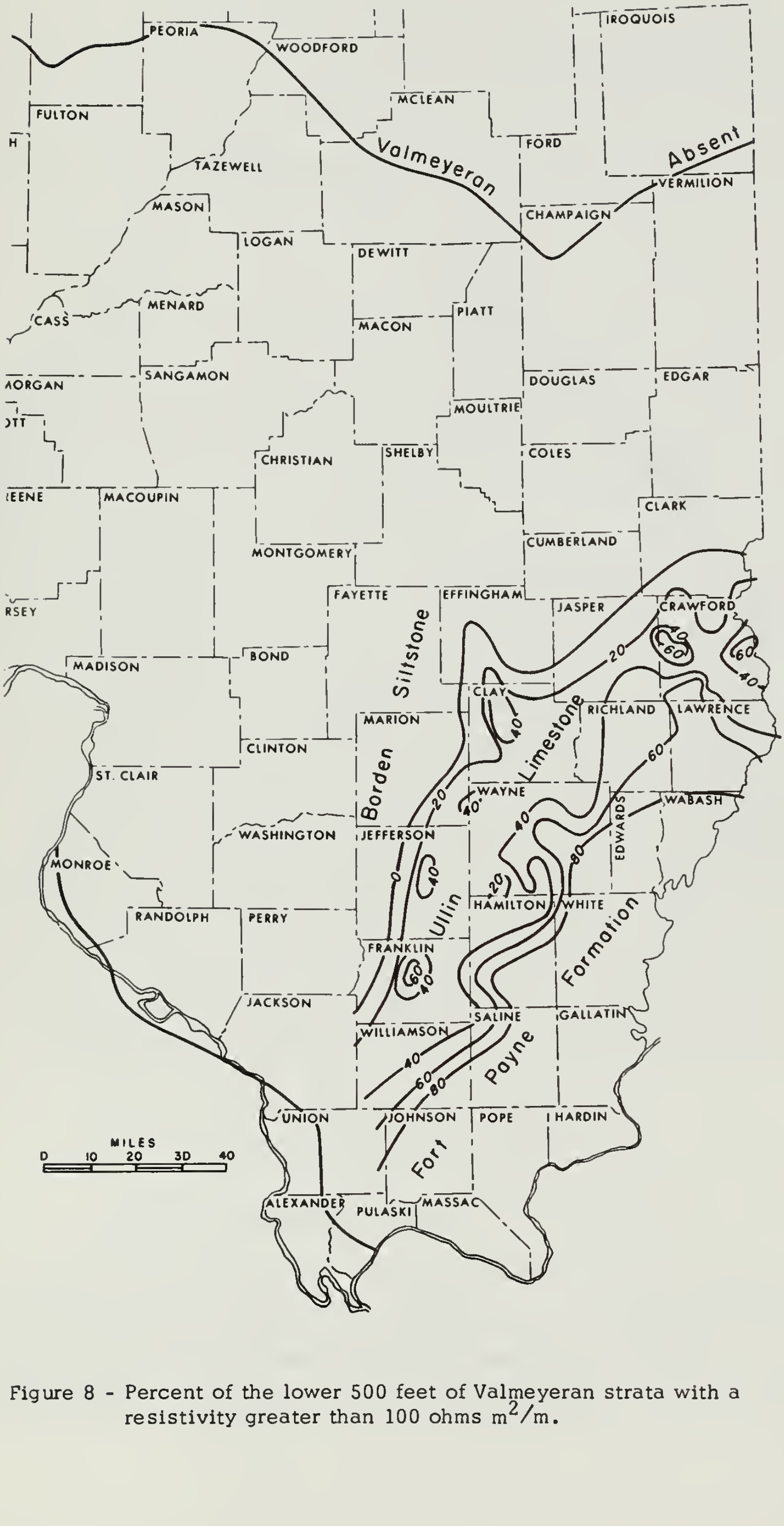


Figure 8 - Percent of the lower 500 feet of Valmeyeran strata with a resistivity greater than 100 ohms m^2/m.

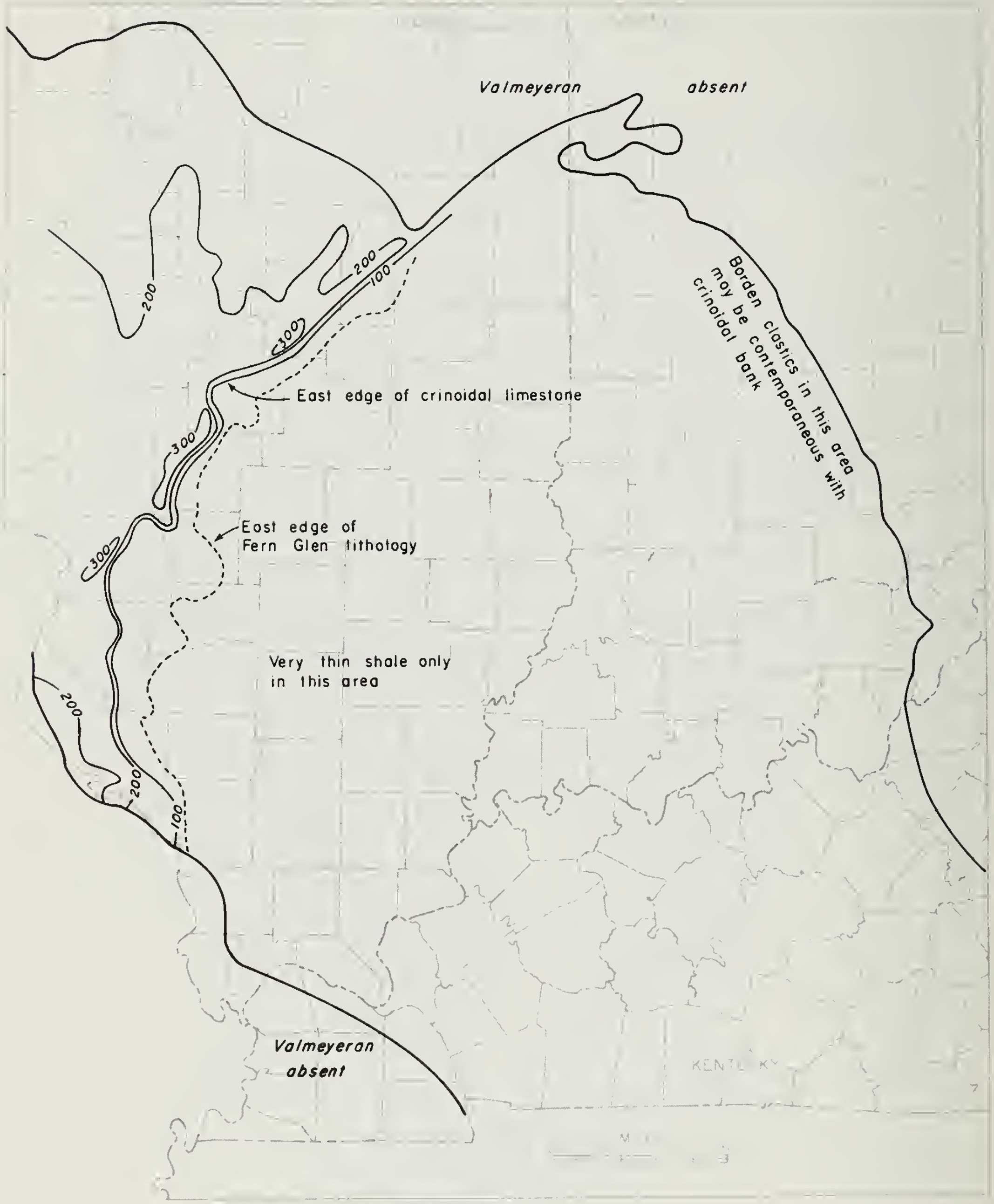


Figure 9 - Thickness of crinoidal limestone bank consisting of the Fern Glen Formation, Burlington Limestone, and Keokuk Limestone.

datum for cross sections and depositional dip computations in this report. Although shown as a horizontal feature on the cross sections, the Chouteau Limestone probably formed the bottom of a shallow, bowl-shaped structural basin that centered in southeastern Illinois and developed before the beginning of Valmeyeran deposition.

The Chouteau to Salem interval varies from 400 feet in western Illinois to 800 feet in the center of the basin. It is about 600 feet over a large area in southern Illinois.

THE CRINOIDAL CARBONATE BANK

Red, green, and gray limestone and shale of the Fern Glen Formation and light-colored, cherty, crinoidal limestone of the Burlington and Keokuk Limestones crop out along the Mississippi River and are part of the type section of the Mississippian System. Similar strata are present in a region from Kansas, across Missouri, into Iowa and Illinois. The cherty limestones abruptly terminate in a sharply defined belt as little as 2 miles wide in the subsurface of central and western Illinois (figs. 1, 9, 10, 11).

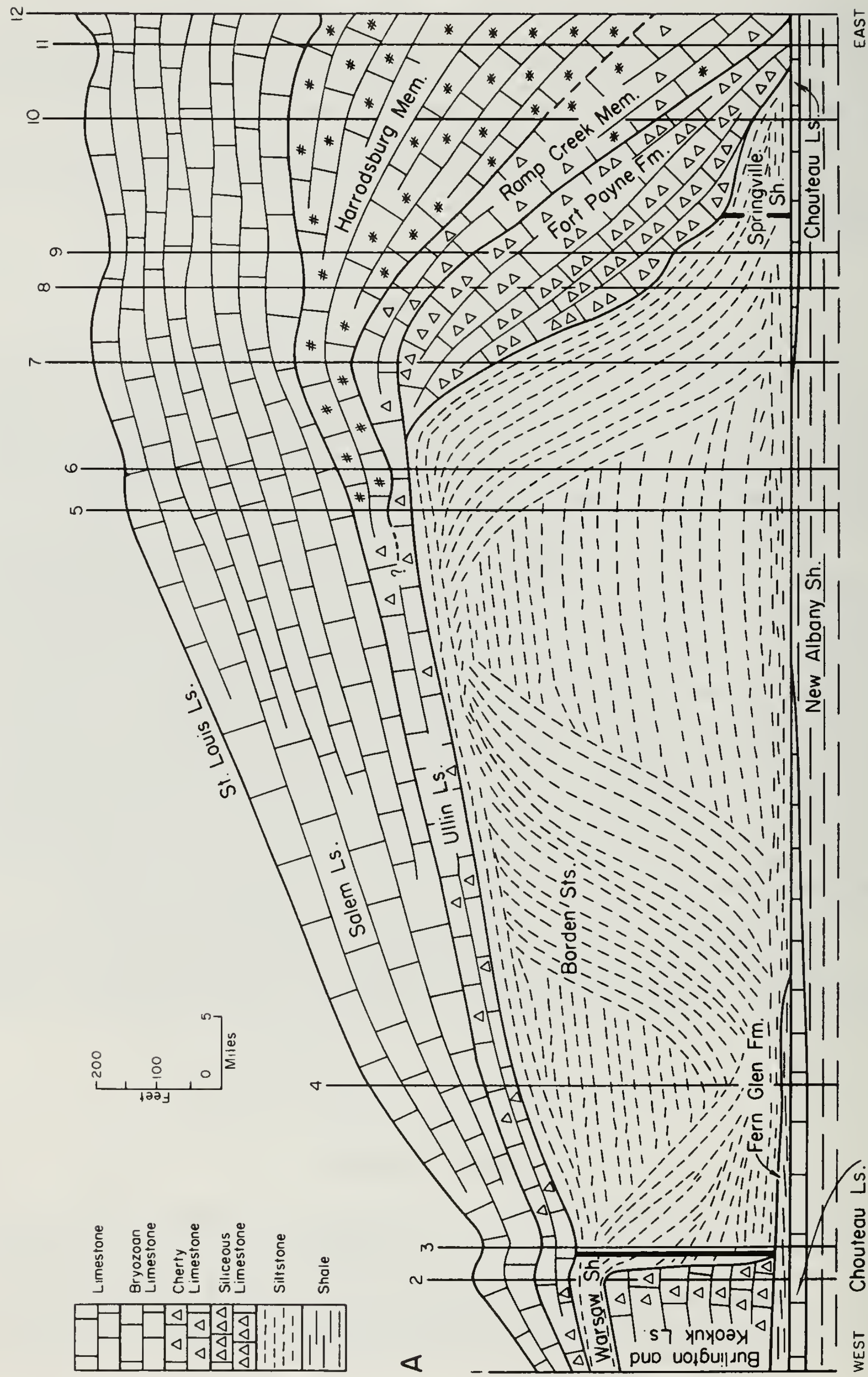
The Burlington and Keokuk Limestones formed a crinoidal carbonate bank that stood 200 to 300 feet above the floor of the deep-water basin to the east. The Burlington and Keokuk do not grade laterally into the clastic sediments that were later deposited adjacent to the limestone bank (Swann, Lineback, and Frund, 1965, fig. 15). Individual beds in the Burlington and Keokuk thin eastward across a two-mile interval until the entire limestone sequence wedges out between the overlying clastics and the Fern Glen Formation. The Warsaw Shale, which overlies the Keokuk Limestone, is equivalent to all except the lower few feet of the Borden Siltstone in southern Illinois. During the deposition of the Fern Glen, Burlington, and Keokuk, only a few feet of mud accumulated above the Chouteau in southern Illinois. Shale of the Fern Glen Formation can be traced a short distance beyond the front of the Burlington-Keokuk bank on the basis of its red and green color (figs. 9, 10, 11). Where the Fern Glen cannot be recognized, it is probably represented by thin shale at the base of the deltaic sequence.

The sudden and uniform margin of the crinoidal carbonates may be related to eastward deepening of water, or to turbidity from clastic sediments advancing from the east. The detailed lithology and stratigraphy of the Fern Glen, Burlington, and Keokuk Formations are not considered here.

THE DELTAIC SEQUENCE

Borden Siltstone

The Borden Siltstone (Cumings, 1922) forms an elongate, tongue-shaped delta immediately east of the margin of the Burlington and Keokuk Limestones (figs. 1, 10, 11). It is continuous with the Borden Group of Indiana but is classified as a formation in Illinois. In Illinois, it consists dominantly of gray to brownish gray, argillaceous, fine siltstone with lesser amounts of silty shale and some greenish gray coarse siltstone or fine sandstone. The Borden is partly cal-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Limestone
Bryozoan Limestone
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3
4
5
6
7
8
9
10
11
12
WEST
EAST
St. Louis Ls.
Salem Ls.
Ullin Ls.
Harrodsburg Mem.
Ramp Creek Mem.
Fort Payne Fm.
Borden Sts.
Springville Sh.
Fern Glen Fm.
Warsaw Sh.
Burlington and Keokuk Ls.
Chouteau Ls.
New Albany Sh.
Chouteau Ls.

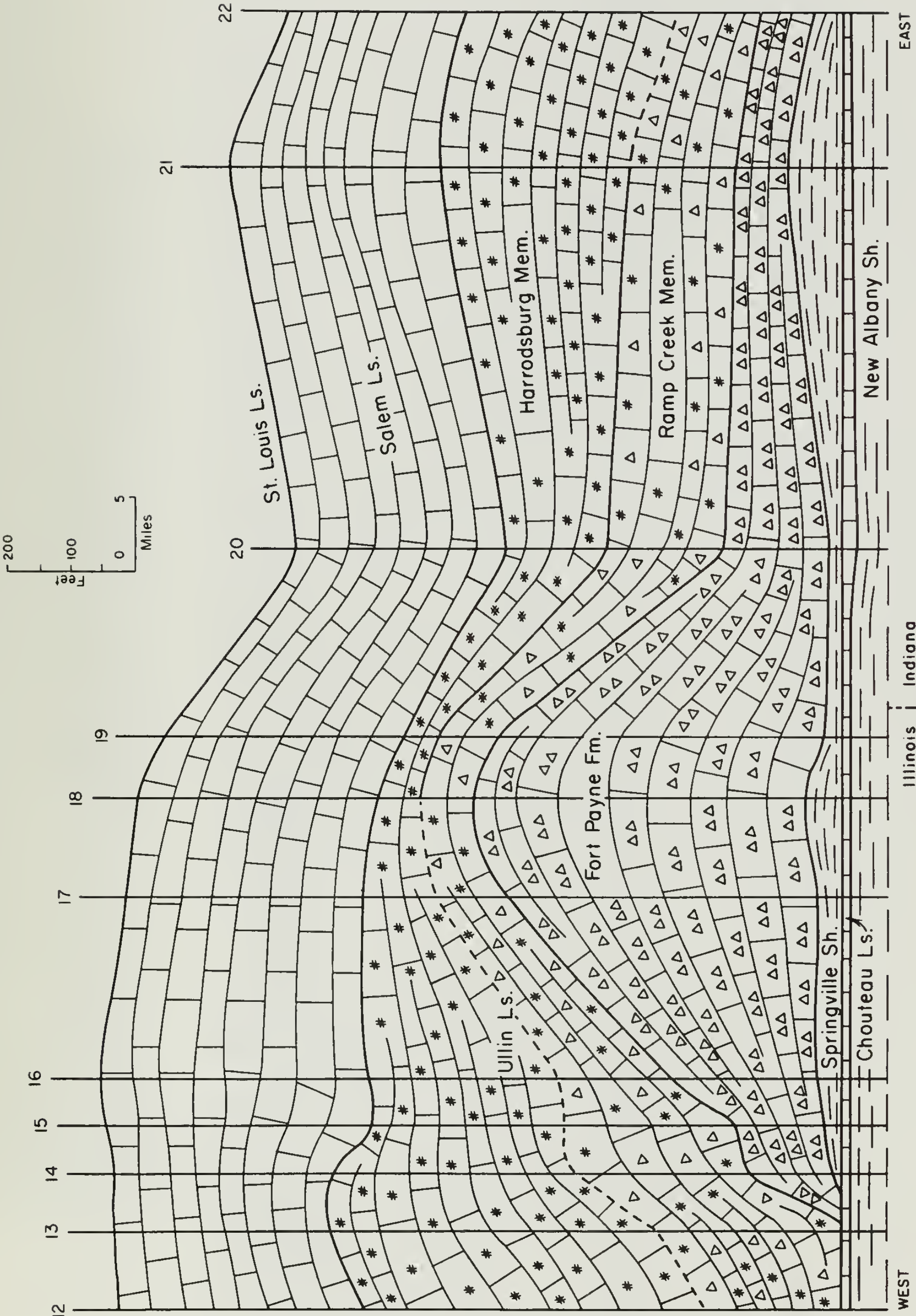


Figure 10 - Continued on next page.

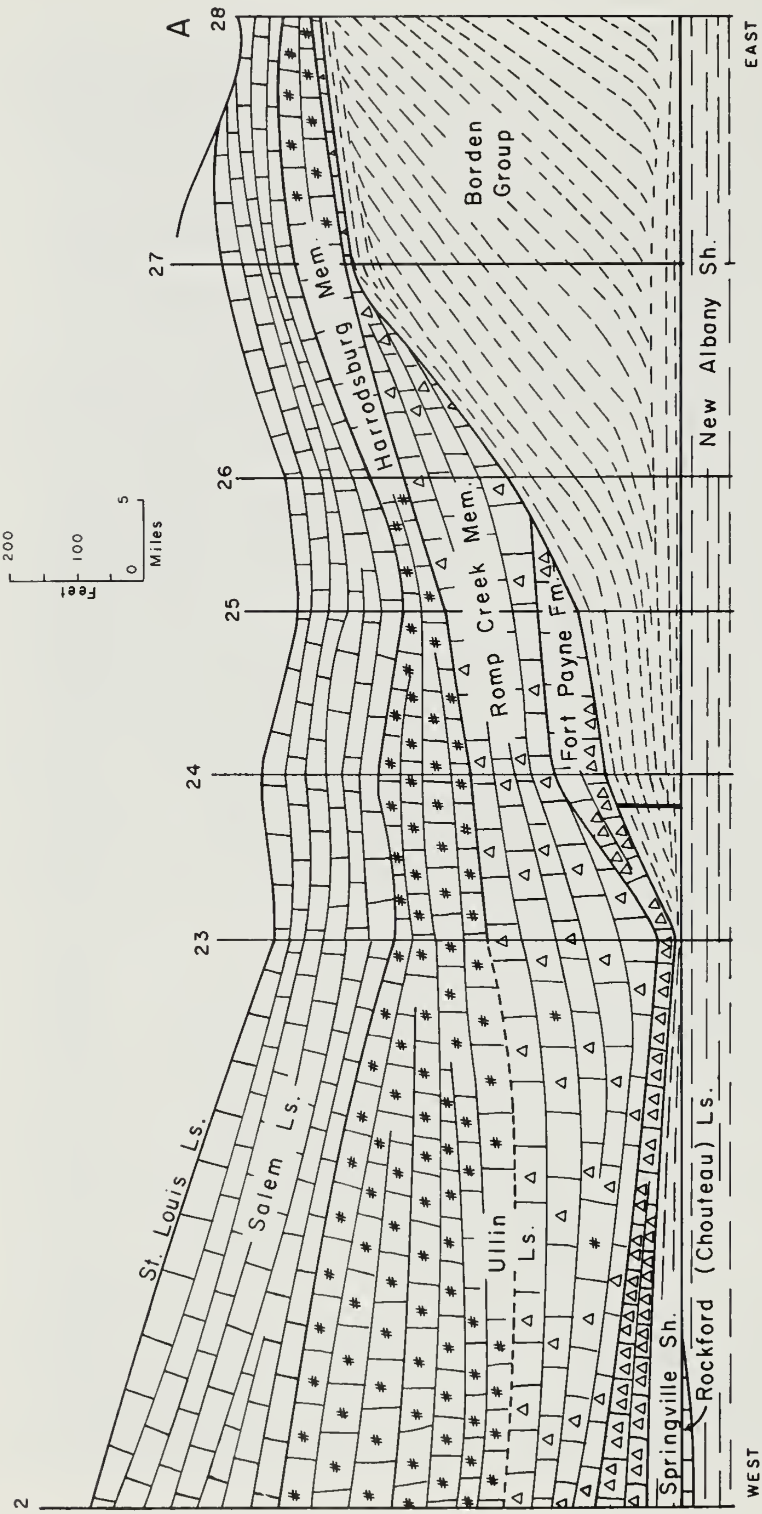


Figure 10 - Cross section A-A' in three parts showing correlation of Valmeyeran units from western Illinois to south-central Indiana (fig. 1). Datum is base of Valmeyeran. Heavy vertical lines show boundaries between Warsaw Shale, Borden Siltstone, and Springville Shale.

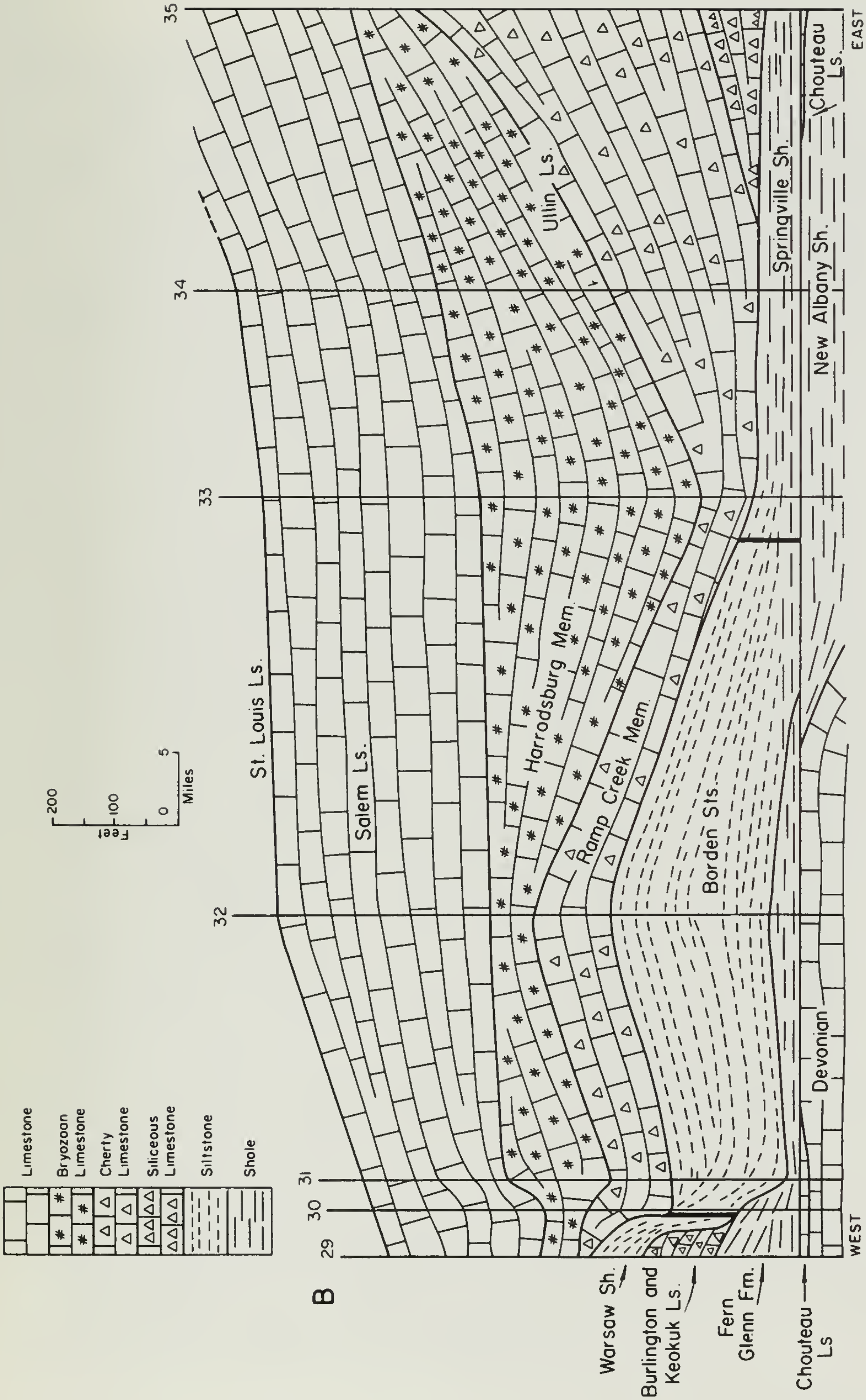
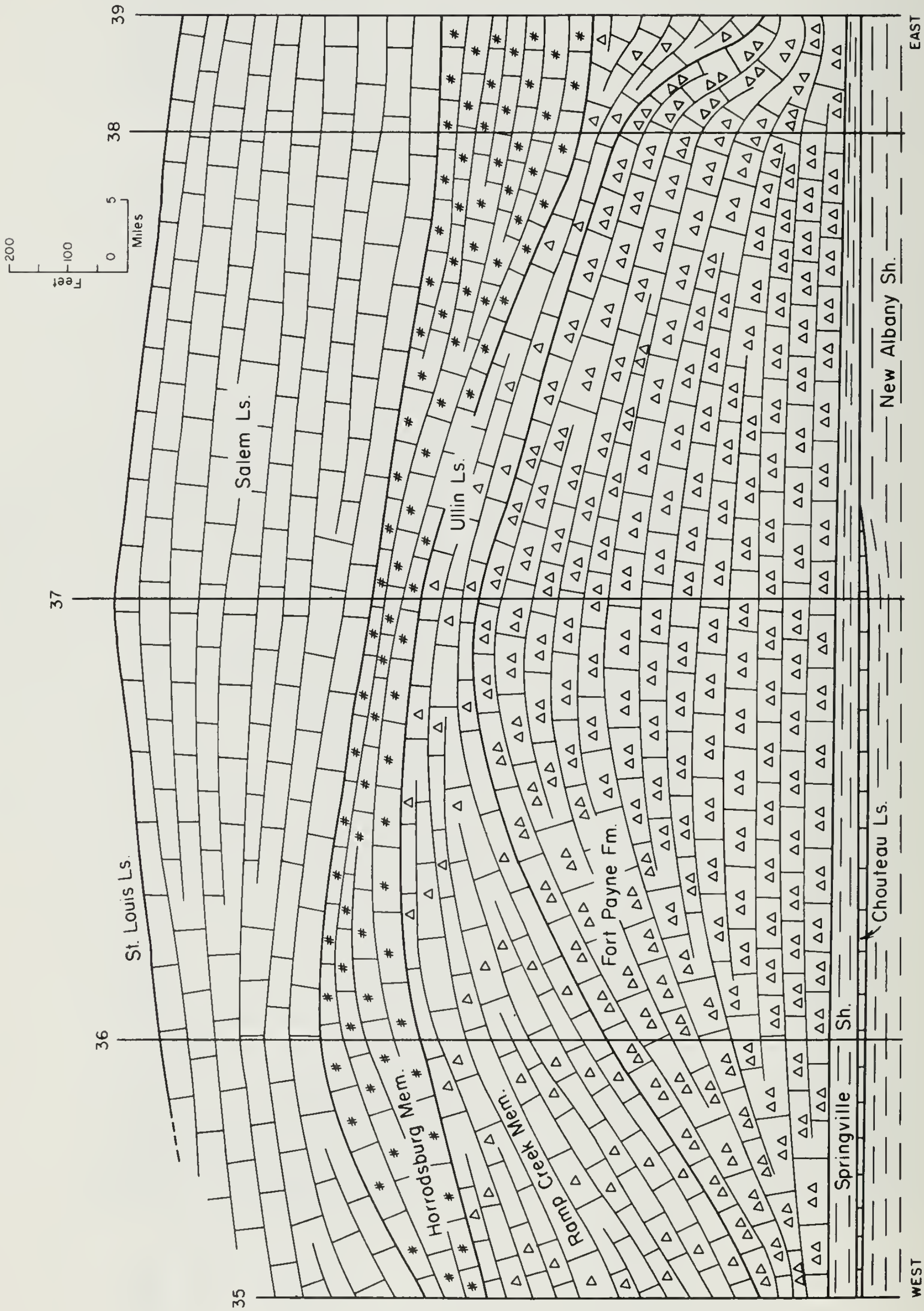


Figure 11 - Continued on next page.


39
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Miles
Salem Ls.
Ullin Ls.
St. Louis Ls.
Horrodsburg Mem.
Ramp Creek Mem.
Fort Payne Fm.
Springville Sh.
Chouteau Ls.
New Albany Sh.

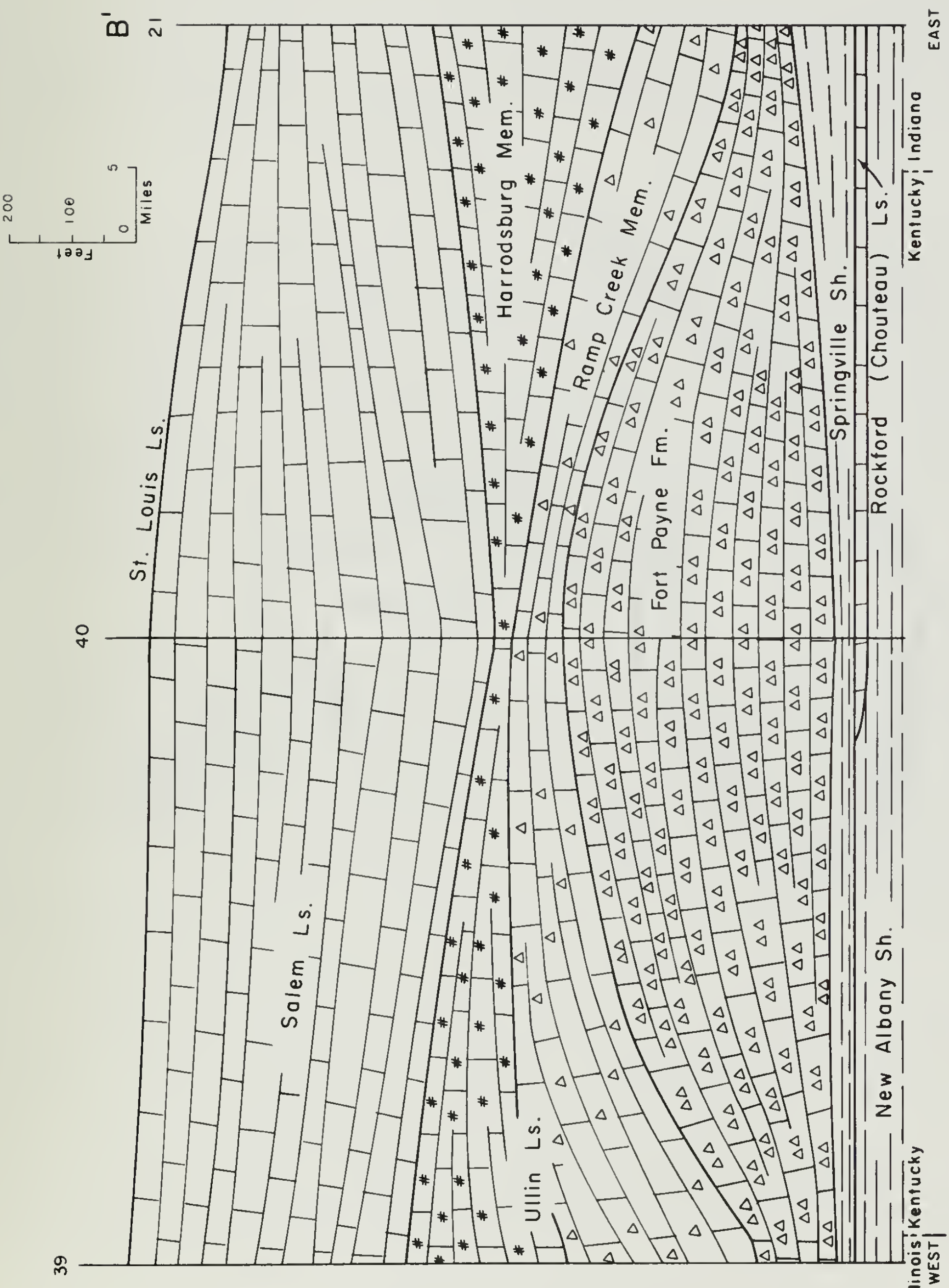


Figure 11 - Cross section B-B' in three parts showing correlation of Valmeyeran units from southwestern Illinois, through Kentucky, to southwestern Indiana (fig. 1). Datum is base of Valmeyeran. Heavy vertical lines show boundaries between Warsaw Shale, Borden Siltstone, and Springville Shale.

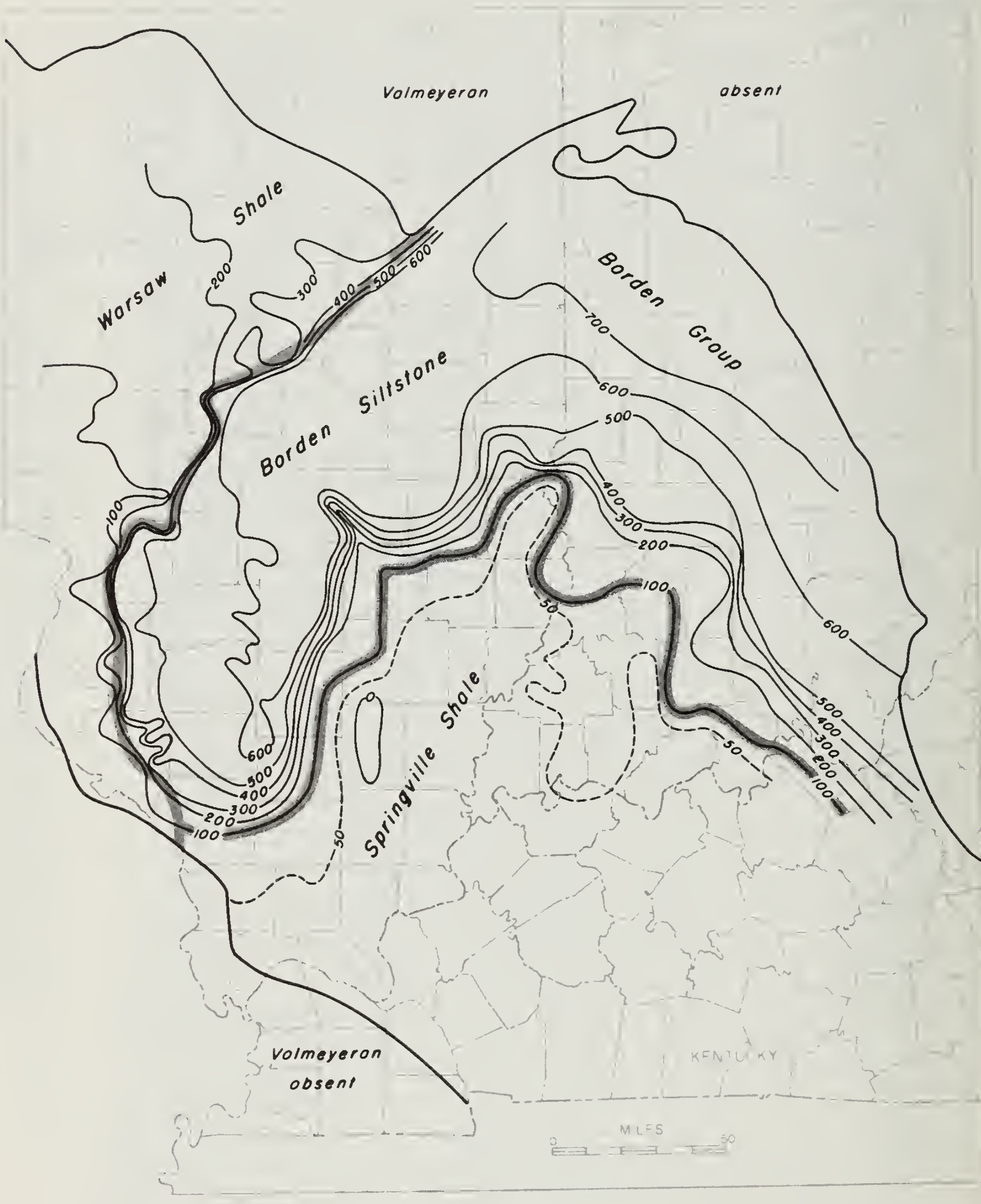


Figure 12 - Thickness of early Valmeyeran deltaic sediments.

careous and glauconitic, and contains some light-colored fossiliferous limestone. It reaches a maximum of 710 feet in thickness (fig. 12).

The Borden Siltstone delta was deposited as a series of southward-developing, imbricated topset, foreset, and bottomset beds (Swann, Lineback, and Frund, 1965). Depositional dips of foreset bedding planes range from 25 to 120 feet per mile towards the delta margin (fig. 7). The Borden delta was built into the deep-water basin by a river.

Warsaw Shale

The siltstone delta followed the margin of the Burlington-Keokuk bank in its southward growth, but it also overrode the carbonate bank. Argillaceous sediment lying above the Keokuk and below the Ullin, Salem, or St. Louis Limestones in western Illinois is called the Warsaw Shale (Hall, 1857) (figs. 2, 10, 11). Shale, siltstone, and sandstone of the Warsaw are continuous with the Borden Siltstone and are equivalent to most of the Borden in and south of Clinton and Christian Counties (Swann, Lineback, and Frund, 1965). The name Warsaw Shale is restricted to use only in the area of the crinoidal bank and is separated from the Borden Siltstone by a vertical cutoff at the depositional pinchout of the Burlington and Keokuk Limestones (fig. 12). The thickness of the Warsaw varies from less than 100 feet to more than 300 feet (fig. 12).

Springville Shale

The Springville Shale (Savage, 1920) primarily represents the deep-water bottomset beds of the Borden delta deposited beyond the outer margin of the foreset beds (figs. 10, 11). A thin basal portion of the Springville is probably equivalent to the Fern Glen, Burlington, and Keokuk. The lower few inches of the type section of the Springville in southwestern Illinois have yielded conodonts and ostracodes typical of the Fern Glen and lower Burlington (Collinson and Scott, 1958).

The Springville Shale consists of greenish gray to dark brownish gray clayey shale and silty shale. In nomenclature, it is arbitrarily separated from the Borden Siltstone at the 100-foot isopach line (fig. 12). It is less than 50 feet thick over most of southeastern Illinois and is absent in places. The Springville is overlain by either the Fort Payne Formation or the Ullin Limestone.

The Springville Shale is the bottomset equivalent of the entire Borden Siltstone. Therefore, the New Providence Shale (basal Borden Group) of southern Indiana is equivalent only to the lower portion of the Springville. The name New Providence, however, is applied in parts of western Kentucky and western Tennessee to the entire unit called Springville in Illinois.

The names Warsaw and Springville are retained for rocks equivalent to the Borden Siltstone because they represent different depositional situations. The Warsaw represents the sediments that overrode the crinoidal bank, the Springville represents the deep-water bottomset beds beyond the delta front, and the Borden represents the main body of the delta.

Regional Implications

The Borden delta in Illinois is the westernmost extent of a vast complex of deltaic sediments that stretches southwestward from Canada and the northern

Appalachians. Devonian sediments of the Catskill delta in New York were succeeded by early Mississippian deltaic clastics that reached as far as Ohio and Michigan to form the Bedford and Berea Formations. During early Valmeyeran time the delta complex advanced into the Illinois Basin.

Southern Illinois had been an area of deep water and slow sedimentation since the beginning of late Devonian time. Only in the western part of the basin was water shallow enough for carbonates to be deposited as the Burlington-Keokuk bank. The Borden Siltstone delta advanced southwestward across Illinois after having been deflected by the carbonate bank. When the delta reached southwestern Illinois, the supply of sediment apparently was no longer sufficient to maintain the advance, and the delta stopped short of the area of present-day Valmeyeran exposure. Further subsidence caused the sea to transgress over the topset part of the delta.

The Borden in Indiana is probably older than the tongue in Illinois, which may represent the last stages of deltaic deposition in the Illinois Basin. Coarse, greenish colored siltstone and fine sandstone characterize the northern portion of the Borden in Indiana. These coarse sediments extend into east-central Illinois, generally into the area of Champaign and Vermilion Counties. The coarse foreset beds thin rapidly southward to form the Carper Sandstone Member of the Borden, which is a deep-water bottomset deposit. Later sediment that formed the bulk of the Borden delta in Illinois is grayish colored fine siltstone and silty shale. The finer grain size of the later sediment may indicate a more distant source area, a more deeply eroded source area, and a less competent river.

Conodonts from the basal portion of the Borden in Indiana are similar to those in the Burlington Limestone and indicate that clastic deposition was taking place in Indiana at the time of deposition of the crinoidal bank in western Illinois (Rexroad and Scott, 1964). In a southward direction in Indiana, progressively younger conodont faunas are found in the basal beds of the Borden (Rexroad and Scott, 1964), indicating the advance of deltaic deposition from north to south.

Topography

The top of a marine delta must necessarily be within a few feet of sea level. An isopach map of the deltaic sediments then becomes a topographic map of the sea floor at the end of deltaic deposition, if the isopachs are considered as isobaths with the datum being the top of the delta. Compaction may cause a 20 to 30 percent thinning.

After Borden deposition ended, a semicircular submarine basin was present in southeastern Illinois and southwestern Indiana (fig. 12). The basin was surrounded by foreset delta slopes that descended into water deeper than 600 feet in a lateral distance of as little as 6 miles (fig. 12). The south end of the basin was open to a sea that may have extended into the Ouachita and Appalachian Geosynclines.

FORT PAYNE FORMATION

The Fort Payne Formation (Smith, 1890) consists of dark-colored, very fine-grained, siliceous, cherty limestone. An irregular tongue-shaped body of

Fort Payne partly filled the deep-water basin formed by the foreset slopes of the Borden delta in southern Illinois and Indiana (fig. 1, 13).

The Fort Payne Formation is over 610 feet thick in Pope County, Illinois, and thins eastward, northward, and westward (fig. 14). It overlies the Springville Shale or Chouteau Limestone in southern Illinois and lies against the foreset slope of the Borden delta (figs. 10, 11, 15).

The tongue of the Fort Payne Formation in southern Illinois is the northernmost part of a large body of siliceous and cherty rocks that extends southward through westernmost Kentucky to Mississippi and Alabama (the type area) and eastward to the Appalachian Mountains.

Outcrops

Three isolated exposures of the Fort Payne Formation are present in southern Illinois. The best of these is a fault slice along the Shawneetown Fault in the NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 36, T. 9 S., R. 7 E., Saline County, near the former community of Horseshoe (fig. 3), where at least 150 feet of steeply dipping Fort Payne is exposed. Fort Payne is also exposed on the flanks of Hicks Dome in Hardin County (NW$\frac{1}{4}$ sec. 32, T. 11 S., R. 8 E.), where it is largely weathered to chert (fig. 3). Eleven feet of chert exposed in the bluff west of Ullin in sec. 21, T. 14 S., R. 1 W., Alexander County, is assigned to the Fort Payne Formation (Appendix A, locality 1). It is the westernmost exposure of Fort Payne in Illinois.

Lithology

The Fort Payne Formation is primarily dark-colored, fine-grained, siliceous and cherty limestone. Quartz silt and clay are present in varying amounts. Fossils are extremely rare, but a few crinoid columnals are present. The chemical and mineralogical content of the Fort Payne from a core in White County (Appendix B, well 19) is summarized in table 1.

Quartz content of the Fort Payne Formation ranges from 8 to 56 percent. Some of the quartz occurs as microscopically visible grains of fine quartz silt, but most of it is an interlocking network of clay-sized quartz particles. When the carbonate is leached from this rock, or upon prolonged surface weathering, a tripolitic porous mass of quartz is left behind. The Fort Payne rocks lying on the Borden delta contain more and coarser quartz silt, but otherwise the rock is essentially the same as in White County.

The calcite content of the Fort Payne varies inversely with the quartz content. CaO content, most of which occurs in calcite, ranges from 46 percent to as little as 2.2 percent. Calcite content is lowest in the argillaceous lower part. The MgO content, mostly in dolomite, is fairly constant and insignificant.

Clay content is small, except for the lower 100 feet of the Fort Payne in the White County core where the carbonate content is very low. Feldspar is present in small amounts, probably as a clastic constituent.

The dark color of the Fort Payne is due to pyrite and organic matter. Organic carbon content averages about 0.5 percent. The preservation of the organic matter may be due to the fine grain size of the rock and to restricted water circulation in the partially closed depositional basin.

Chert is commonly present as dark-colored nodules and beds throughout the Fort Payne, but in cores chert forms only a small portion of the total volume

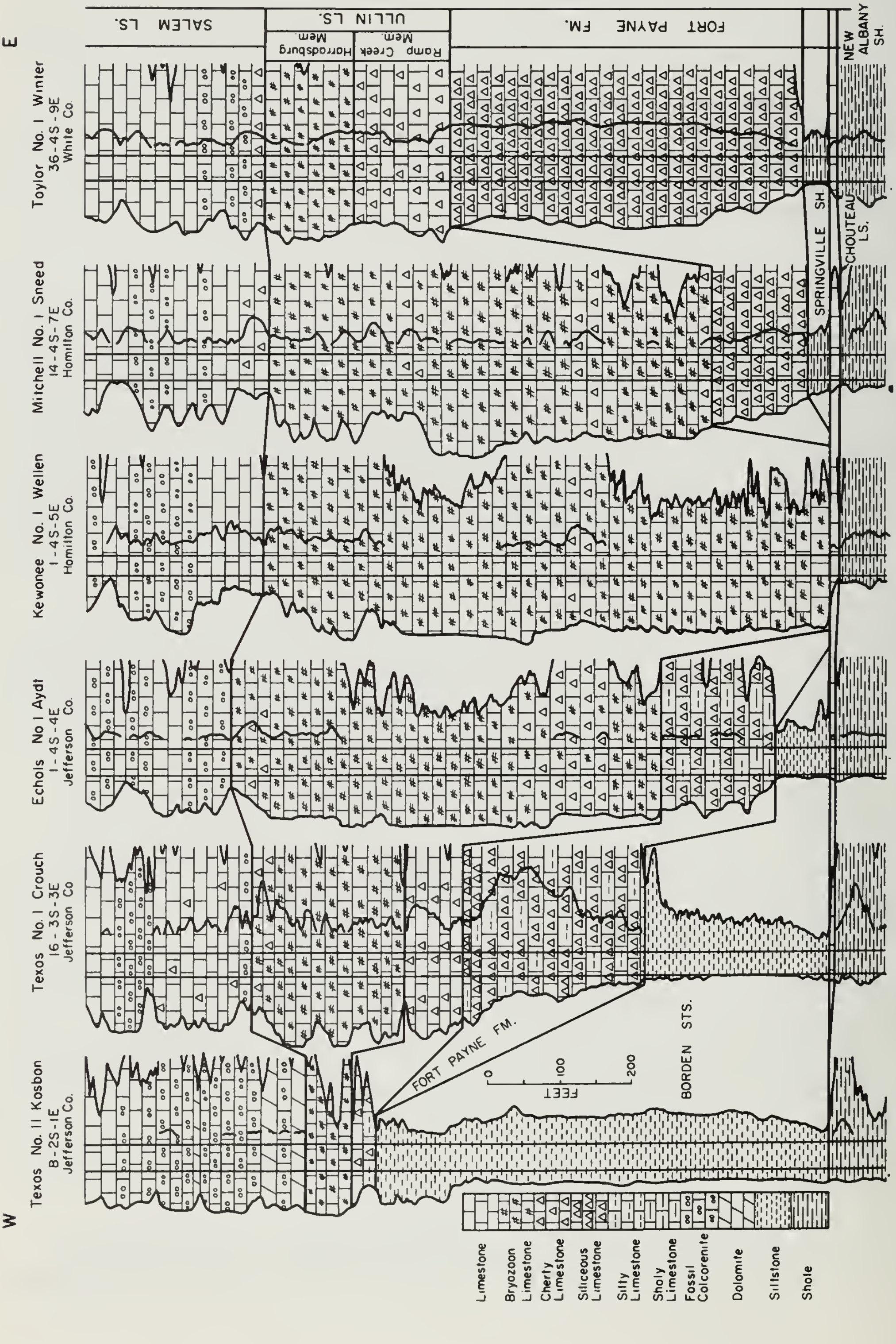


Figure 13 - Cross section showing major lower Valmeyeran lithologic units in Jefferson, Hamilton, and White Counties (fig. 3).

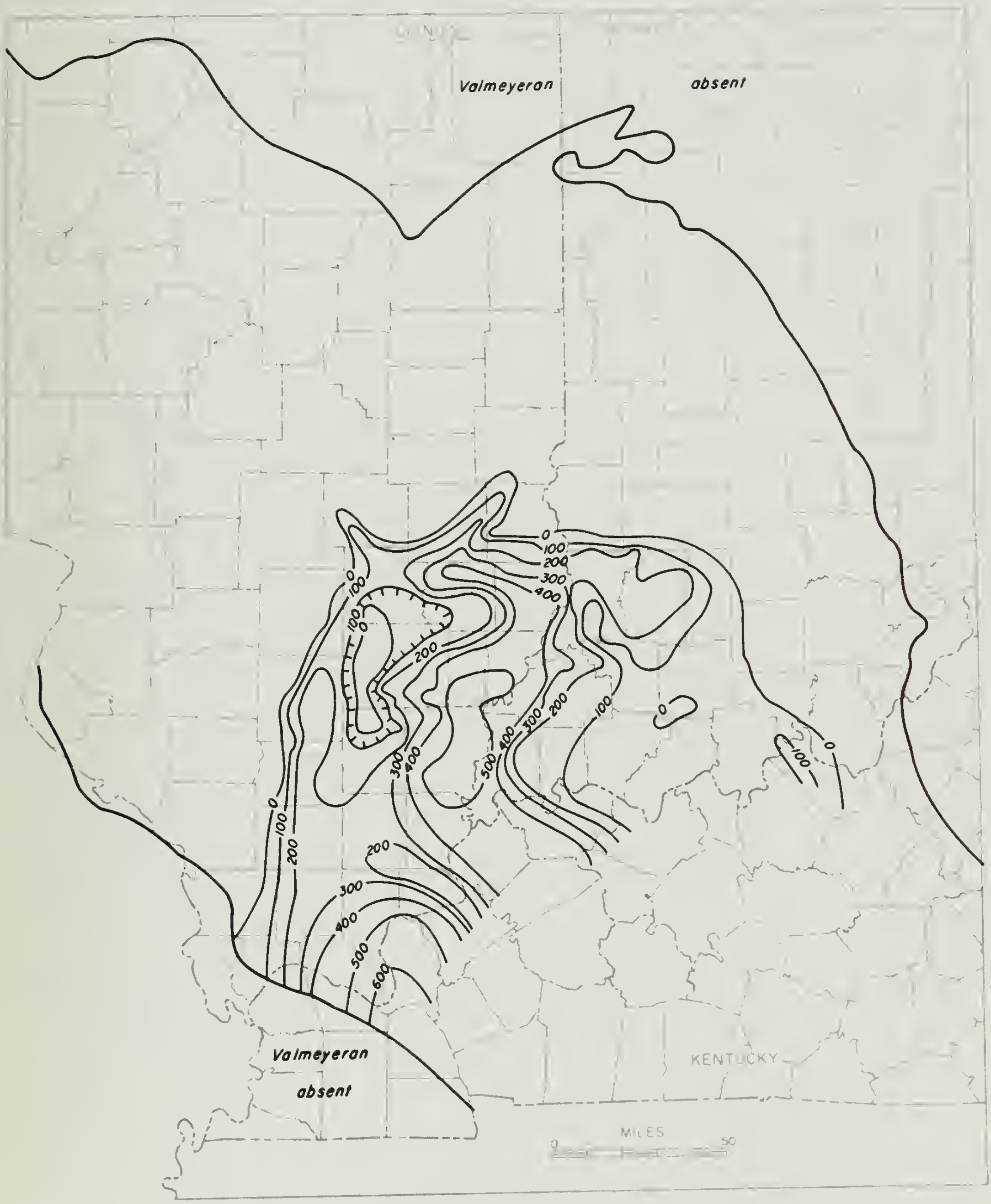
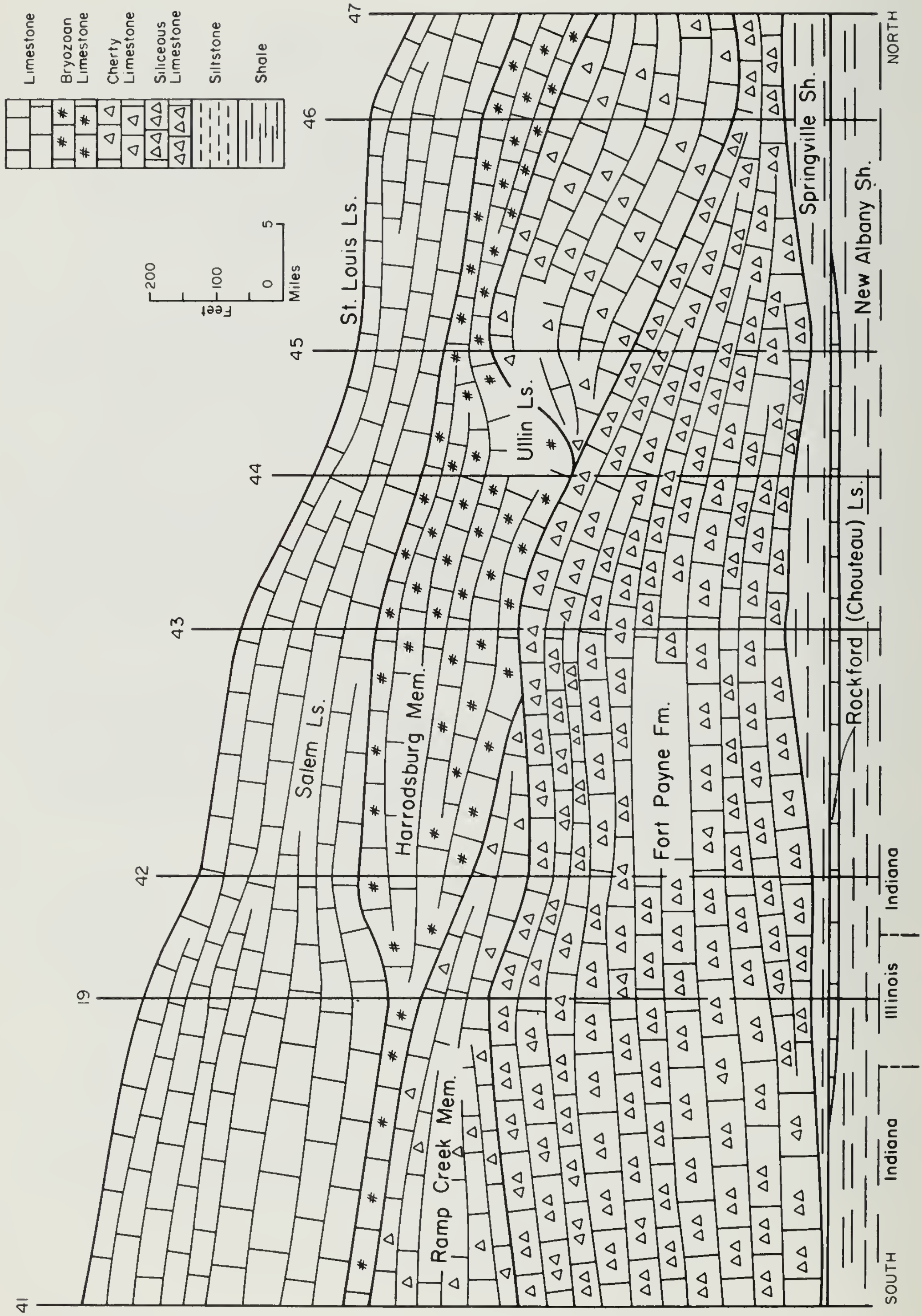


Figure 14 - Thickness of the Fort Payne Formation.


Limestone
Bryozoan Limestone
Cherty Limestone
Siliceous Limestone
Siltstone
Shale
Feet
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100
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44
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42
19
41
St. Louis Ls.
Salem Ls.
Harrodsburg Mem.
Ullin Ls.
Fort Payne Fm.
Ramp Creek Mem.
Springville Sh.
New Albany Sh.
Rockford (Chouteau) Ls.
NORTH
SOUTH
Indiana
Illinois
Indiana

C

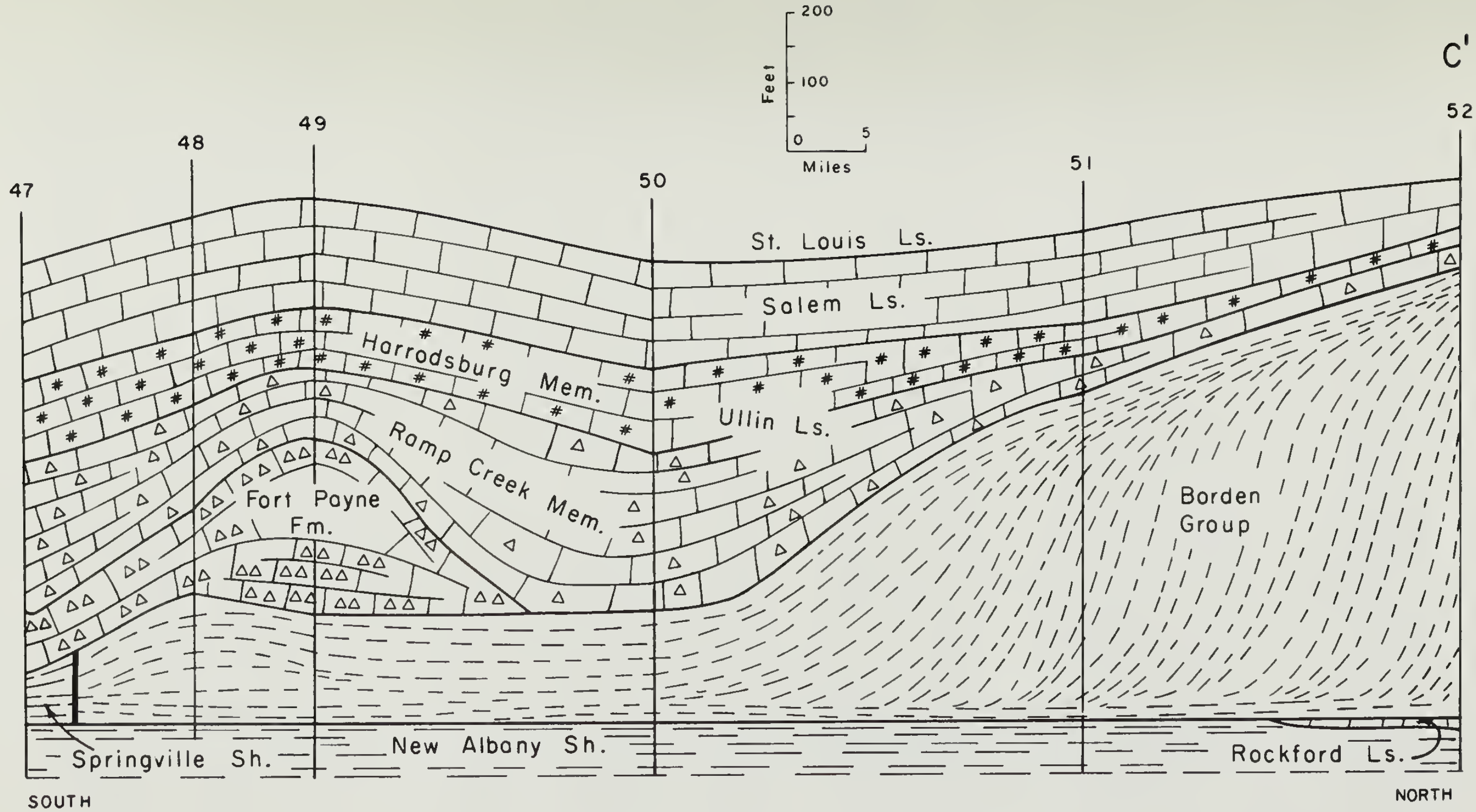


Figure 15 - Cross section C-C' in two parts showing correlation of Valmeyeran units along the Illinois-Indiana state line from southwestern Indiana north to Parke County, west-central Indiana (fig. 1). Datum is base of Valmeyeran. Heavy vertical line shows boundary between Springville Shale and Borden Group.

TABLE 1 - CHEMICAL AND MINERALOGICAL ANALYSES OF THE ULLIN LIMESTONE AND THE FORT PAYNE FORMATION[1] (COMPOSITIONS IN PERCENT)

Sample	Depth (feet)	Feldspar (X-ray)	Quartz (X-ray)	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	CO_2	S	Ignition loss	Carbon
1	3891	0.8	6.6	9.0	0.2	0.65	0.2	2.0	48.8	0.10	0.18	39.23	0.20	39.53	0.0
2	3941	1.3	34.2	44.4	0.2	1.50	0.5	0.8	28.2	0.15	0.37	22.87	0.42	23.23	0.26
3	3991	0.9	7.8	11.2	0.2	1.30	0.4	2.5	46.8	0.11	0.34	36.85	0.31	37.19	0.24
4	4091	1.8	56.4	68.3	0.3	1.20	0.6	2.4	12.4	0.21	0.36	11.42	0.43	11.04	0.03
5	4141	2.2	28.1	43.1	0.3	3.10	1.1	3.2	24.6	0.26	0.75	20.89	0.69	21.54	0.54
6	4191	2.0	23.2	36.9	0.3	2.20	0.8	2.0	31.2	0.23	0.60	26.02	0.58	26.90	0.61
7	4241	2.5	51.7	60.3	0.3	2.80	1.0	1.7	15.6	0.29	0.65	15.16	0.52	16.29	0.54
8	4291	2.6	45.5	60.7	0.3	3.50	1.2	2.0	16.8	0.31	0.78	15.50	0.61	16.17	0.73
9	4391	3.2	35.6	51.9	0.4	3.95	2.2	1.4	19.0	0.38	1.03	17.10	0.82	17.64	0.50
10	4441	7.7	25.7	62.7	0.9	16.20	4.8	2.6	2.2	0.91	4.22	3.34	0.93	6.78	0.61

[1] Sample 1, Ullin Limestone (3760-3920 ft.); sample 2-10, Fort Payne Formation (3920-4440 ft.). Samples from a core of the Superior C-17 Ford well in sec. 27, T. 4 S., R. 11 W., White County, Illinois. X-ray by H. D. Glass; chemical analyses by R. H. Burroughs and D. B. Heck.

of the rock. In surface outcrops, there is usually an abundance of secondary chert formed by weathering.

Some of the Fort Payne has small-scale contortions and lenticular bedding that resemble structures of siltstones. Although the small-scale bedding and inclined depositional dips indicate deposition by currents, deltaic structure has not been demonstrated.

Environment of Deposition

The Fort Payne sediment is a mixture of terrigenous quartz, clay, and feldspar with chemically or biologically precipitated quartz, chert, and carbonate. The source for the clastic material in most of the formation may have been from the south. The Fort Payne rocks that lie on the margin of the Borden delta contain some sediment derived from the delta. The Fort Payne was deposited under conditions that favored formation of pyrite and preservation of organic matter.

Relationships to Adjacent Units

Bedding in the Fort Payne Formation dips parallel to the foreset bedding where the Fort Payne lies on the foreset slope of the Borden delta (fig. 4), and, therefore, the Fort Payne does not grade laterally into the Borden. Bedding planes in the main body of the Fort Payne also dip parallel to the upper boundary in at least two places (figs. 5, 6). Beds of the overlying Ullin Limestone are parallel to the boundary, and there is no evidence of lateral gradation between the Fort Payne and the Ullin.

The Fort Payne was deposited as an irregular, tongue-shaped body with sloping sides. The top and bottom depositional surfaces in White County are separated by over 500 feet of rock (figs. 10, 13). The upper surface dips westward until it meets the lower surface in an area in Hamilton County where the Fort Payne is absent. These surfaces again diverge westward, but with an eastward dip, so that the Fort Payne thickens on the foreset slope of the delta in Jefferson County. The bounding surfaces again come together at a point near the top of the delta where the Fort Payne is overlapped (figs. 10, 13).

After deposition of the Fort Payne, narrow topographic depressions, at least 600 feet deep in places, remained in the sea floor in southern Illinois (fig. 16). Carbonate sediment of the Ullin Limestone later filled these depressions.

ULLIN LIMESTONE

The name Ullin Limestone is proposed for the light-colored, fine- to coarse-grained, bryozoan- and crinoid-rich limestone strata that overlie the Fort Payne Formation (or the Borden, Springville, Warsaw, or Chouteau Formations where the Fort Payne is absent) and underlie the Salem Limestone (figs. 2, 10, 11, 13, 15). The Ullin Limestone filled the elongate depressions between the tongue of the Fort Payne Formation and the Borden delta (fig. 16). The Ullin reaches a maximum thickness in excess of 800 feet in Hamilton County, Illinois, and is 500 feet thick in southwestern Indiana (fig. 17). The light-colored limestone sequence extends beyond the depressions across the top of the Fort Payne tongue and the top of the Borden delta. It pinches out between the Warsaw and Salem Formations in western Illinois (fig. 17).

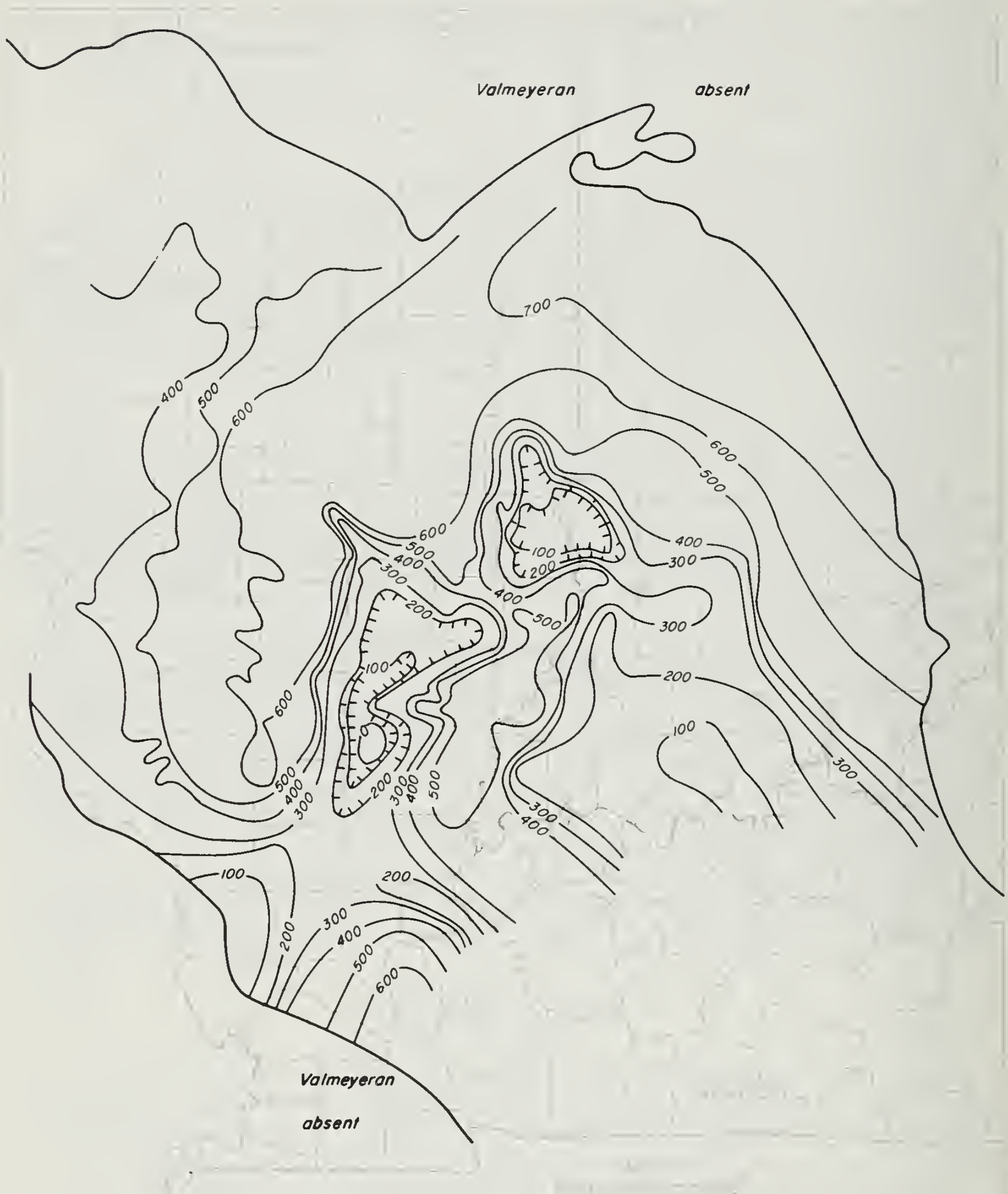


Figure 16 - Thickness of Valmeyeran rocks below the Ullin Limestone.

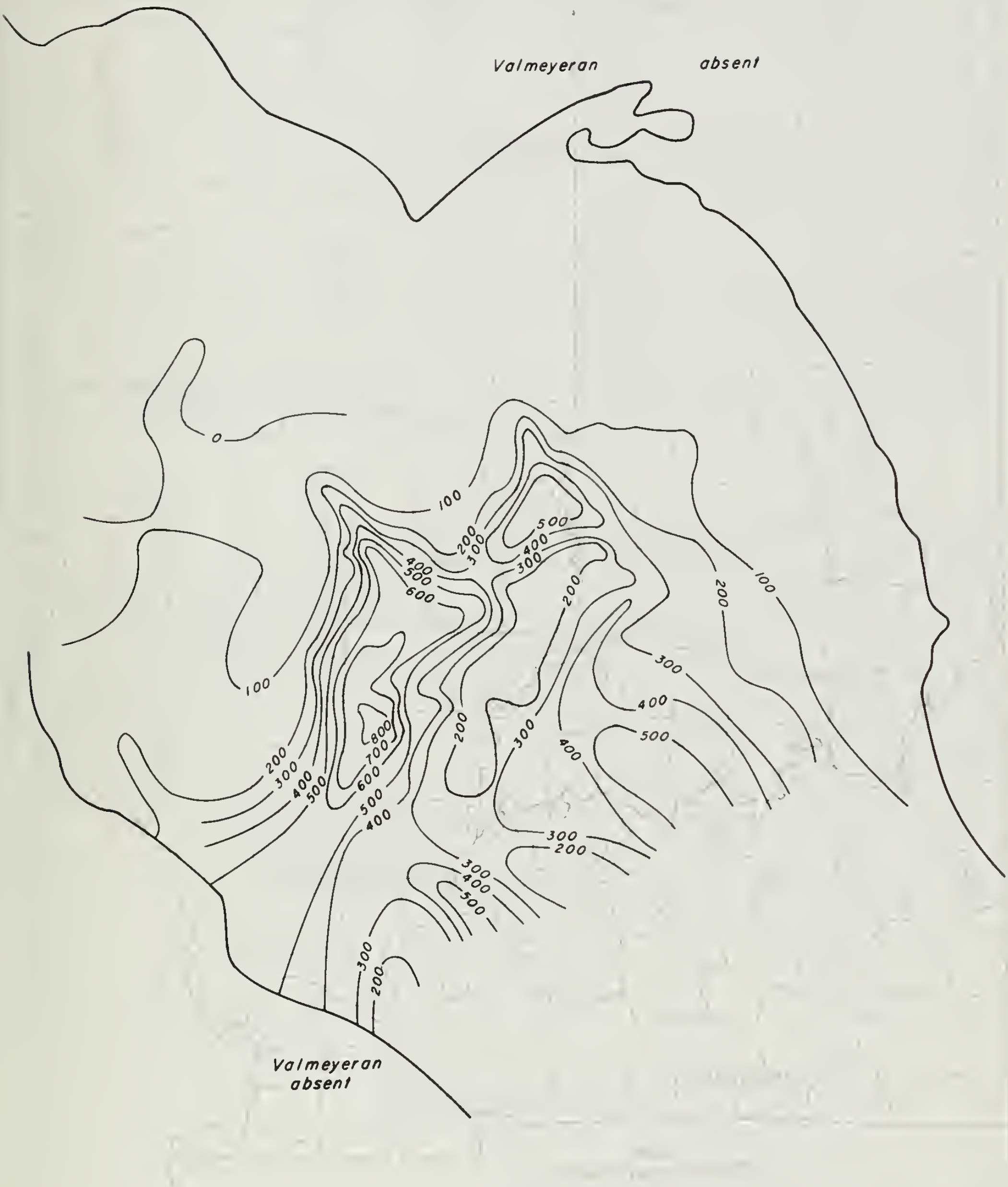
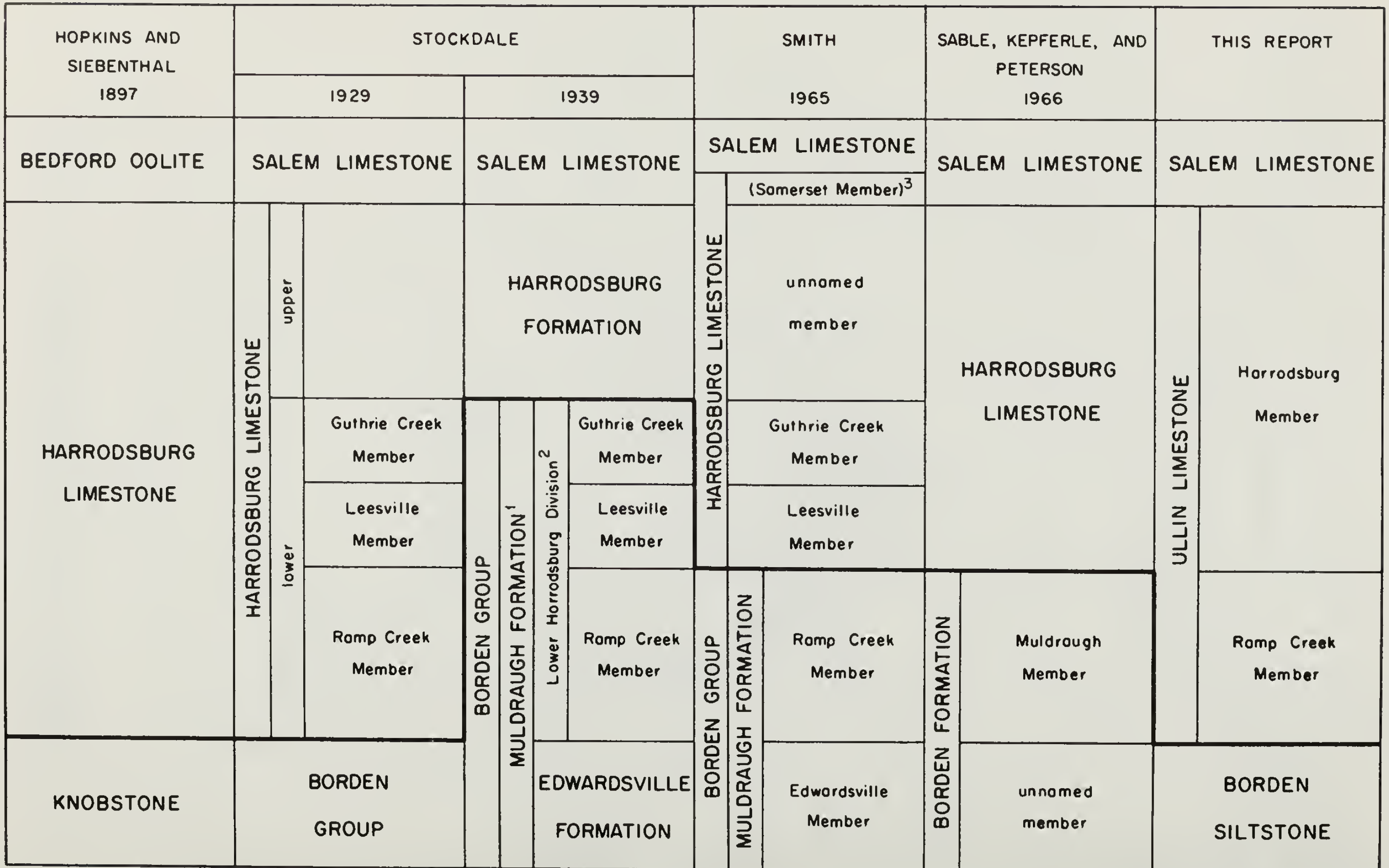


Figure 17 - Thickness of the Ullin Limestone.



[1]Kentucky nomenclature [2]Indiana nomenclature [3]Name not used in Indiana

Figure 18 - Development of nomenclature for part of the Valmeyeran. The heavy line marks the top of the Borden of various authors.

A two-fold division of the Ullin Limestone can be traced in the subsurface over most of southwestern Indiana and southern Illinois. The upper member of the Ullin, the Harrodsburg Member, is generally lighter colored, coarser grained, and purer than the lower member, the Ramp Creek Member. The Harrodsburg and Ramp Creek Members are very similar, and in about one-third of their areas in Illinois they cannot be separated lithologically. Where the Ullin is thickest, as in Hamilton County, all of the Ullin is light-colored bryozoan-rich calcarenite (figs. 10, 13). In other areas, the Ullin can be separated into its two members because the Ramp Creek contains more chert and crinoidal debris, is darker in color, and is glauconitic in places. Where the limestone sequence is thin, as on the crest of the Borden delta or on the highest parts of the Fort Payne tongue, both members become more crinoidal and are indistinguishable at places.

In southwestern Indiana, and adjacent parts of Illinois east of the Fort Payne tongue, the Ramp Creek Member can generally be separated from the Harrodsburg Member. The Ramp Creek is more cherty, glauconitic, silty, and in general contains limestone that is less pure than limestone in the Harrodsburg. The Ramp Creek contains some fine-grained siliceous and silty limestone where it overlies siltstone of the Borden in Kentucky and southern Indiana.

Nomenclature

The Ullin Limestone is equivalent to the Harrodsburg Limestone as originally described by Hopkins and Siebenthal in 1897. Since that date these rocks have undergone several nomenclatural revisions in Indiana and Kentucky (fig. 18). The chief revision has been the restriction of the name Harrodsburg to the upper part of the original Harrodsburg.

Stockdale (1929, 1931) subdivided the Harrodsburg into upper and lower divisions. He further subdivided the lower part into three members (fig. 18). He later (1939) restricted the name Harrodsburg in Kentucky to the upper Harrodsburg of his earlier reports and correlated the Guthrie Creek, Leesville, and Ramp Creek Members with the upper part of his Muldraugh Formation in Kentucky. The Muldraugh Formation is a body of westward-thickening, calcareous, cherty rock that formed the upper formation of the Borden Group in Kentucky (Stockdale, 1939). The names Ramp Creek (1929) and Muldraugh (1939) appear to have been applied by Stockdale to the same unit. Therefore, the name Ramp Creek has priority. Stockdale, and later Smith (1965), assumed lateral gradation from siltstone of the Borden into the fossiliferous carbonates of the Ramp Creek, and both included siltstone of the Borden (Edwardsville Member) in the Muldraugh Formation. The Ramp Creek overlies the Borden and in this report the Ramp Creek is included as a member in the Ullin Limestone.

Smith (1965) further revised the Harrodsburg in the type area, restricting the name Harrodsburg to the upper bryozoan-rich part of the limestone (fig. 18). He concluded that the Leesville and Guthrie Creek Members are lithologically more closely related to the overlying part of the Harrodsburg than they are to the Ramp Creek Member, and therefore placed the base of the Harrodsburg Limestone at the base of the Leesville Member (fig. 18). He also included a thin argillaceous limestone correlated with the Somerset Member of the Salem Limestone of Kentucky. The Somerset is excluded from the Harrodsburg in this report.

Recent study by the United States Geological Survey in Kentucky has shown that the carbonate rocks called Muldraugh in Kentucky overlie the foreset slopes of the Borden delta with a sharp contact, do not interfinger with or grade laterally into siltstone, and thicken rapidly westward in Kentucky as the siltstone thins

(Edward Sable, personal communication). The Muldraugh is classified as a member of the Borden Formation (Wier, Gualtieri, and Schlanger, 1966). The Harrodsburg in Kentucky has been revised to include the Leesville and Guthrie Creek (Sable, Kepferle, and Peterson, 1966).

Type Area

The type section of the Ullin Limestone is compiled from exposures in secs. 14, 21, and 22, T. 14 S., R. 1 W., Alexander and Pulaski Counties, Illinois (Dongola 15-minute quadrangle; Appendix A, localities 1-3). The formation is named for the town of Ullin, Illinois, in sec. 23, T. 14 S., R. 1 W., Pulaski County (fig. 3).

The lower Valmeyeran strata in Union, Alexander, and Pulaski Counties have been assigned to several formations. The cherty strata here called Ramp Creek were referred to the Burlington and Keokuk by Worthen (1868), Weller and Krey (1939), and Weller and Ekblaw (1940). The white limestone of the Harrodsburg Member was referred to the Warsaw, Salem, or Warsaw-Salem for many years, but the name Harrodsburg Limestone has been used recently (Desborough, 1961).

The Ramp Creek Member is 490 feet thick in wells near the Ullin type sections (Appendix C, wells 1 and 2). It consists of medium gray to medium brownish gray, cherty, very fine-grained calcarenite and calcilutite. Bryozoan and crinoid fragments that make up the limestone are so small they generally can be recognized only in thin section. The Ramp Creek thins northward in Union County to about 100 feet near Anna. Where it has been heavily weathered, most of it has been altered to chert (Appendix A, locality 1).

As the Ramp Creek Member of the Ullin thins northward in Union County, it is overlain by a northward-thickening body of very light-colored, coarse-grained, bryozoan-crinoid calcarenite and calcirudite assigned to the Harrodsburg Member. The Harrodsburg is about 140 feet thick at the Ullin type section (Appendix A, locality 3) and is over 400 feet thick in the vicinity of Anna and Jonesboro, 11 miles north. The Harrodsburg becomes progressively coarser grained from bottom to top. It has little chert or other impurities. Although it is well cross-stratified, it usually has a massive appearance.

The Ullin Limestone in Union and Pulaski Counties contains a conodont fauna dominated by Taphrognathus varians (C. W. Collinson, personal communication). This fauna is similar to that of the overlying Salem, but it is different from the older fauna of the Warsaw and Borden, which is dominated by Gnathodus texanus.

The Ullin Limestone is overlain by the Salem Limestone. The Salem is also a bryozoan-crinoid calcarenite, but contrasts with the Harrodsburg Member in texture and color. The Harrodsburg has a uniform coarse-grained texture with darker colored crinoid fragments in a white matrix of frondescent and some ramose bryozoan fragments. It has well-developed, large-scale, low-angle, planar crossbeds. In contrast, the Salem is dark-colored, usually finer grained, lacks the white bryozoan matrix, is oolitic in places, and is not as well cross-bedded (Appendix A, locality 3). The contact between the Salem and Ullin can be observed at several places in Union County where it is sharp, nongradational, and in many places slightly irregular.

Other Outcrops in Illinois

The Ullin Limestone can be traced across the crest of the Borden delta to the outcrop in Monroe County, Illinois (fig. 3), where the upper part has been included in the Salem Limestone and the lower part in the Warsaw Formation (Weller and Weller, 1939; Baxter, 1960). Bryozoan-crinoid calcarenite and calcirudite, here assigned to the Harrodsburg Member of the Ullin Limestone, was named the Kidd Member of the Salem Limestone by Baxter (1960) (Appendix A, locality 4). Harrodsburg has priority and replaces the name Kidd.

About 30 feet of argillaceous crinoidal calcarenite below the Harrodsburg in Monroe County, previously included in the upper part of the Warsaw Formation, are here assigned to the Ramp Creek Member of the Ullin Limestone. The term Warsaw is restricted in this region to the underlying calcareous shale (Appendix A, locality 4).

The Ullin Limestone also crops out at Hicks Dome in Hardin County (T. 11 S., R. 8 E.) (fig. 3). In Hardin County the limestone above the Fort Payne was called the Harrodsburg Limestone by Baxter and Desborough (1965). The Harrodsburg and Ramp Creek Members can be separated in the subsurface near Hicks Dome. At Hicks Dome the Ullin is about 60 feet thick (Baxter and Desborough, 1965), but the Ramp Creek Member thickens to 300 feet and the Harrodsburg Member to 260 feet in the eastern Hardin County subsurface (fig. 11).

Origin

The Ullin Limestone is almost entirely formed of the finely broken remains of bryozoans and crinoids. The fragmentation, the uniform texture, and the large-scale cross-stratification indicate prolonged transportation by currents. In many places, such as Hamilton County, the Ullin Limestone exhibits a uniform lithology through a thickness of 800 feet, even though the basal portion was deposited in water deeper than 600 feet and the top in shallow water. In the type area, the Ullin becomes progressively coarser grained upward and the cross-beds change upward from low angle to high angle. This suggests shorter transportation of the fossil fragments and shallower water as the depressions were filled.

The bryozoans and crinoids, which provided the bulk of the sediment of the Ullin Limestone, probably lived in shallow water. A shallow-water carbonate platform developed on the top of the Borden delta as the sea transgressed across the topset beds. Another shallow-water area existed on the highest parts of the Fort Payne tongue. Crinoid and bryozoan debris were carried off the platforms by currents and deposited in the deep water of the depressions between the delta and the Fort Payne tongue. After the depressions were filled, conditions changed, and a slightly different shallow-water carbonate rock (Salem) was deposited.

OVERLYING ROCKS

The Salem Limestone overlies the Ullin Limestone in Illinois and Indiana (fig. 2). It contains fine-grained dolomite and limestone that vary from silty and argillaceous to pure. Anhydrite also occurs sparsely. Lenticular beds of oolitic to nonoolitic fossil calcarenite are interbedded with the fine-grained rocks.

In the subsurface, the Salem can be separated from the subjacent Harrodsburg Member of the Ullin Limestone because the Salem is darker in color, lacks the white bryozoan matrix, exhibits better rounding and sorting of the fossil fragments, has oolites and endothyrid foraminifers, and contains fine-grained argillaceous or silty carbonates. The contact is generally sharp, and there appears to be no significant intergrading between the Ullin and Salem Limestones.

The Salem represents shallower water and a higher energy environment than the Ullin, as indicated by more rounding of fossils and the formation of oolites.

The Salem was deposited in the broad shallow-water basin left after the submarine depressions in southeastern Illinois were filled by the Ullin Limestone.

SUMMARY OF DEPOSITIONAL HISTORY

A shallow-water carbonate bank, a delta, and bodies of deep-water siliceous sediment and deep-water limestone were deposited in the Illinois Basin during early Valmeyeran time. Each represents a different depositional event. The irregular deposition of these units resulted in major changes in relief on the ocean floor and a marked influence on sedimentation.

The depositional events can be summarized as follows:

1. Crinoidal carbonates of the Burlington and Keokuk Limestones were deposited under shallow-water conditions in western Illinois. The abrupt depositional margin of the crinoidal bank formed a topographic rise on the sea floor facing a deep-water basin in southern Illinois.
2. Deltaic sediments advancing from the east reached into Indiana and Illinois. One tongue of deltaic clastics was deflected by the carbonate bank southwestward across Illinois and also partly overrode the carbonate bank. The Borden Siltstone, Warsaw Shale, and Springville Shale form the clastic sequence.
3. After deltaic deposition ceased, the foreset slopes of the deltaic sediments surrounded a semicircular deep-water basin in southern Illinois and southwestern Indiana. The basin was partially filled with a southward-thickening tongue of dark-colored, cherty, siliceous limestone of the Fort Payne Formation.
4. Topographic depressions left after deposition of the Fort Payne were filled by light-colored fossiliferous limestone of the Ullin Limestone.
5. The Salem Limestone was deposited in a shallow-water basin left after the filling of the last topographic features.

APPENDIX A

Geologic Sections

Locality 1.—Type sections of Ullin Limestone; bluffs along north side of Cache River Valley, SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 21, T. 14 S., R. 1 W., Alexander County, Illinois (Dongola 15-minute quadrangle).

Section above is chert rubble.

	Thickness (feet)
ULLIN LIMESTONE	
Ramp Creek Member	
Chert, light gray, weathers brownish gray, in beds 6 to 12 inches thick; some samples from nearby exposures show unreplaced dark gray, very fine-grained limestone; top not exposed	49.5
FORT PAYNE FORMATION	
Chert, argillaceous, rubbly zone	1.0
Chert, silty and argillaceous, light gray, weathers brown; beds 6 to 18 inches thick	10.0
Total Fort Payne Formation	11.0
SPRINGVILLE SHALE	
Shale, siliceous, soft parting	0.5
Shale, very siliceous, brown, deeply weathered, platy; beds 6 to 8 inches thick; base not exposed	5.0
Measured Springville Shale	5.5

Section begins at base of exposure about 50 feet above road level.

Locality 2.—Type sections of Ullin Limestone; section lies in middle of Ramp Creek Member and shows unsilicified lithology; section located on north side of road at west end of county road bridge over Mill Creek in SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 22, T. 14 N., R. 1 W., Alexander County, Illinois (Dongola 15-minute quadrangle).

Chert rubble exposed for 20 feet above section.

	Thickness (feet)
ULLIN LIMESTONE	
Ramp Creek Member	
Limestone, biocalcarenite, fine-grained, light brownish gray; poorly developed beds 3 to 12 inches thick; light gray chert in nodules and bands	5.0
Limestone, bryozoan-crinoid calcarenite, brownish gray, very fine-grained; poorly developed laminations; beds 6 to 24 inches thick and poorly developed; medium gray chert beds and nodules; base not exposed	22.5
Measured Ramp Creek Member	27.5

Base of section at road level.

Locality 3.—Type sections of Ullin Limestone; Columbia Quarry Section measured along road into pit and in westernmost part of quarry, April 15, 1966, located SW¼ NE¼ sec. 14, T. 14 S., R. 1 W., Pulaski County, Illinois (Dongola 15-minute quadrangle).

Section covered by thick soil.

	Thickness (feet)
SALEM LIMESTONE	
Limestone, bryozoan-crinoid calcarenite, coarse-grained, oolitic, medium brownish gray; irregular wavy beds 6 to 12 inches; poorly developed cross-beds; some chert; contact with Ullin below is very slightly irregular, but lithologies above and below are very similar	10.0
ULLIN LIMESTONE	
Harrodsburg Member	
Limestone, bryozoan-crinoid calcarenite with bryozoan matrix, light brownish gray; coarse-grained at top; small-scale cross-bedding	10.0
Chert and limestone, light gray chert in beds 1 to 3 inches thick in light brownish gray calcarenite limestone	1.0
Limestone, calcarenite, coarse-grained, light gray; poorly defined beds 1 to 3 feet thick; large-scale cross-beds more inclined than in lower part; section inaccessible in quarry face	41.0
Limestone, calcarenite, coarse-grained, light gray; one bed, with steeply dipping cross-beds	2.0
Limestone, calcarenite to calcirudite, coarse-grained, light gray; bryozoan matrix with coarser crinoid fragments than lower units; beds thicker (1 to 2 feet) than lower units	11.0
Limestone, calcarenite to calcirudite, coarse-grained, light gray; matrix of light gray ramose and frondescent bryozoans with fragments of darker colored crinoids; fragments well oriented; some chert; some brachiopods and other fossils; stylolites; beds 6 to 24 inches thick, large-scale low-angle cross-bedding poorly developed	33.0
Limestone, bryozoan-crinoid calcarenite, light gray to light brownish gray, massive; poorly developed beds 6 to 18 inches thick and low-angle large-scale cross-bedding	28.5
Limestone, bryozoan-crinoid calcarenite, medium gray; beds 12 to 18 inches thick; large-scale low-angle planar cross-bedding with some smaller scale cross-bedding superimposed; some chert	10.0
Total Harrodsburg Member	136.5
Ramp Creek Member	
Limestone, bryozoan-crinoid calcarenite, fine-grained, medium dark gray to dark gray; beds 6 to 12 inches; chert in dark gray bands 6 inches apart	15.0
Measured Ullin Limestone	151.5

Section begins at lowest point in quarry floor.

Locality 4.—Section measured in stream and along road beginning in SE¼ SE¼ sec. 36, T. 4 S., R. 10 W., and continuing uphill northeasterly into SW¼

NW$\frac{1}{4}$ sec. 31, T. 4 S., R. 9 W., Monroe County, Illinois (Renault 15-minute quadrangle). This section is located one-half to one-quarter of a mile north of section published by Baxter (1960) as type section of Kidd Member of Salem Limestone.

Section above is poorly exposed and overlain by loess.

	Thickness (feet)
SALEM LIMESTONE	
Fults Member	
Limestone, calcilutite, very fine-grained, argillaceous, silty, dolomitic, light brownish gray; thin (1 to 3 inches) irregular beds; top of unit not exposed	10.0
ULLIN LIMESTONE	
Harrodsburg Member	
Limestone, calcarenite, fine-grained, fine matrix, very light gray; thick beds 1 to 3 feet lower becoming thin and irregularly bedded in upper part	14.0
Limestone, bryozoan-crinoid calcirudite, very coarse-grained, light brownish gray; poorly developed thick beds; small-scale cross-bedding	7.5
Limestone, crinoid calcarenite, coarse-grained, light brownish gray; bryozoan matrix decreasing upward; uniform texture; irregular beds, thin, poorly developed; massive in fresh exposure; small-scale cross-bedding	5.5
Limestone, calcarenite, fine- to coarse-grained, light brownish gray; thin, poorly developed beds	5.5
Limestone, crinoid-bryozoan calcirudite, coarse-grained, light brownish gray; irregular thin beds to massive, poorly developed cross-bedding; chert zone at top	11.0
Limestone, crinoid-bryozoan calcarenite, fine-grained, light brownish gray; bedding irregular 1 to 12 inches	6.0
Limestone, crinoid-bryozoan calcarenite, medium- to fine-grained, somewhat argillaceous, fossiliferous, light brownish gray; thick to thin irregular beds; burrows on bedding surface; base not exposed	3.0
Limestone, calcarenite, fine- to coarse-grained, some calcirudite, somewhat argillaceous, light to medium brownish gray; thin irregular beds, mostly covered	13.0
Limestone, bryozoan-crinoid calcarenite, coarse-grained, light brownish gray; irregular bedding 3 to 12 inches thick	10.0
Total Harrodsburg Member	75.5
Ramp Creek Member	
Limestone, fine-grained, argillaceous, light brownish gray; poorly developed irregular beds; fossiliferous with many brachiopods; burrows on bedding surfaces; some chert; some shaly limestones	10.5
Limestone, fine- to coarse-grained, argillaceous, light gray; irregular wavy beds; burrows on bedding surfaces; some chert	6.0
Limestone, bryozoan-crinoid-brachiopod calcarenite to calcirudite; poorly developed 3- to 12-inch beds; largely covered	11.0

	Thickness (feet)
Ramp Creek Member, continued	
Limestone, crinoid-bryozoan calcarenite, siliceous, light to medium brownish gray; single bed	1.0
Limestone, calcilutite, argillaceous, siliceous, light to medium brownish gray; single bed; sharp contact with shale below	1.0
Total Ramp Creek Member	29.5
Total Ullin Limestone	105.0
WARSAW SHALE	
Shale, calcareous, blocky to platy, fossiliferous, greenish gray, medium hard; coarse-grained, siliceous, argillaceous, crinoid calcirudite in lenticular beds 0 to 3 feet thick; some limestone beds occupy channels 3 feet deep	11.0
Limestone, crinoid calcirudite, coarse-grained, argillaceous, light gray; lenticular bed	1.0
Shale, calcareous, hard, blocky, fossiliferous, greenish gray, weathers brown	15.0
Limestone, crinoid calcirudite, coarse-grained, argillaceous, light brown to light brownish gray; irregular lenticular beds 0 to 18 inches; siliceous; some shale	4.0
Shale, calcareous, greenish gray, weathers brown, soft; some bryozoans and crinoids	9.0
Measured Warsaw Shale	40.0

Base of exposure is at road level at base of hill.

APPENDIX B

List of Wells Used for Cross Sections

1. Kiskadden No. 1 Fischer, sec. 27, T. 5 N., R. 8 W., Madison County, Illinois.
2. Luttrell No. 1 Buehler, sec. 26, T. 5 N., R. 7 W., Madison County, Illinois.
3. Aurora No. 1 Schmidt, sec. 19, T. 5 N., R. 6 W., Madison County, Illinois.
4. Doran No. 1 Widmer, sec. 5, T. 3 N., R. 5 W., Madison County, Illinois.
5. Texas No. 11 Kasban, sec. 8, T. 2 S., R. 1 E., Jefferson County, Illinois.
6. Magnolia No. 1 Schulik, sec. 22, T. 2 S., R. 1 E., Jefferson County, Illinois.
7. Magnolia No. 1 Jones, sec. 10, T. 3 S., R. 2 E., Jefferson County, Illinois.
8. Texas No. 1 Crouch, sec. 16, T. 3 S., R. 3 E., Jefferson County, Illinois.
9. Redwine No. 1 Prudential, sec. 27, T. 3 S., R. 3 E., Jefferson County, Illinois.
10. Echols No. 1 Aydt, sec. 1, T. 4 S., R. 4 E., Jefferson County, Illinois.
11. Rider and Freeze No. 1 Scrivner, sec. 27, T. 3 S., R. 5 E., Hamilton County, Illinois.
12. Kewanee No. 1 Wellen, sec. 1, T. 4 S., R. 5 E., Hamilton County, Illinois.
13. Eason No. 1 Smith and Little, sec. 2, T. 4 S., R. 6 E., Hamilton County, Illinois.
14. Texas No. 3 Minton, sec. 20, T. 4 S., R. 7 E., Hamilton County, Illinois.
15. Mitchell No. 1 Sneed, sec. 14, T. 4 S., R. 7 E., Hamilton County, Illinois.
16. Anding No. 2 McIntosh, sec. 31, T. 3 S., R. 8 E., White County, Illinois.
17. Taylor No. 1 Winter, sec. 36, T. 4 S., R. 9 E., White County, Illinois.
18. Phillips No. 1 Garr, sec. 31, T. 4 S., R. 11 E., White County, Illinois.
19. Superior C-17 Ford, sec. 27, T. 4 S., R. 14 W., White County, Illinois.
20. Indiana Farm Bureau Co-op No. 1 Rowe, sec. 36, T. 5 S., R. 13 W., Posey County, Indiana.
21. T. & H. Corp. No. 1 Princeton Mining, sec. 10, T. 6 S., R. 10 W., Vanderburgh County, Indiana.
22. O'Neal No. 1 Cornell, sec. 17, T. 5 S., R. 9 W., Warrick County, Indiana.
23. Ohio No. 1 Philomenia, sec. 28, T. 4 S., R. 4 W., Spencer County, Indiana.
24. Triangle No. 1 Huber, sec. 10, T. 3 S., R. 3 W., Dubois County, Indiana.
25. Tamblyn No. 1 Bullard, sec. 16, T. 2 S., R. 2 W., Crawford County, Indiana.
26. Vickers No. 1, Brown, sec. 26, T. 2 S., R. 1 W., Crawford County, Indiana.
27. Cameron and Assoc. No. 1 Combs and Duncan, sec. 20, T. 2 S., R. 2 E., Crawford County, Indiana.
28. Stoll No. 1 Leonhardt, sec. 36, T. 2 S., R. 4 E., Harrison County, Indiana.
29. Robison No. 1 Buckhorn, sec. 6, T. 6 S., R. 6 W., Randolph County, Illinois.
30. Halbert No. 1 Ross, sec. 33, T. 5 S., R. 6 W., Randolph County, Illinois.
31. Hammer No. 1 Huey, sec. 35, T. 5 S., R. 6 W., Randolph County, Illinois.
32. Stanolind No. 1 Hayer, sec. 20, T. 7 S., R. 4 W., Jackson County, Illinois.
33. Lambert No. 1 Hagler, sec. 28, T. 10 S., R. 2 W., Jackson County, Illinois.
34. Little Egypt No. 1 Basler, sec. 35, T. 11 S., R. 1 W., Union County, Illinois.
35. Midcontinent No. 1-A Herren, sec. 12, T. 14 S., R. 1 E., Pulaski County, Illinois.
36. Kahle No. 1 Harvick, sec. 23, T. 14 S., R. 3 E., Massac County, Illinois.
37. Rigney and Dodson No. 1 Lewis, sec. 18, T. 16 S., R. 7 E., Pope County, Illinois.

38. Shell No. 1 Page, sec. 21, T. 12 S., R. 9 E., Hardin County, Illinois.
39. Lucas No. 1 Herrin, sec. 11, T. 12 S., R. 10 E., Hardin County, Illinois.
40. Pure, Ashland, and Browning No. 1 Walker, 22-N-24, Webster County, Kentucky.
41. Carter No. 1 Graulich, sec. 4, T. 7 S., R. 14 W., Posey County, Indiana.
42. Continental No. 1 Cooper, sec. 13, T. 3 S., R. 14 W., Gibson County, Indiana.
43. Superior No. 1 Braselton, sec. 24, T. 2 S., R. 12 W., Gibson County, Indiana.
44. Brown No. 1 Bingham, sec. 16, T. 1 S., R. 11 W., Gibson County, Indiana.
45. Cardinal No. 1 Pielemier, sec. 21, T. 1 N., R. 11 W., Knox County, Indiana.
46. White No. 1 Harrell, don. 11, T. 2 N., R. 9 W., Knox County, Indiana.
47. Midwest No. 1 Jackson, don. 54, T. 3 N., R. 9 W., Knox County, Indiana.
48. Sun No. 1 Ott, don. 182, T. 4 N., R. 9 W., Knox County, Indiana.
49. Duncan No. 1 Blann, sec. 15, T. 5 N., R. 9 W., Knox County, Indiana.
50. Froderman No. 1 Harris, sec. 2, T. 8 N., R. 10 W., Sullivan County, Indiana.
51. Smith No. 5 Smith, sec. 15, T. 11 N., R. 9 W., Vigo County, Indiana.
52. Carter No. 1 Blair, sec. 30, T. 14 N., R. 8 W., Parke County, Indiana.

APPENDIX C

Sample Studies

Well 1.—Mary Vaughn No. 1 Lawrence Ragsdale SW¼ NW¼ sec. 18, T. 14 S., R. 1 E., Pulaski County, Illinois. Sample set 26983. Study by Elwood Atherton.

	Thickness (feet)	Bottom (feet)
PLEISTOCENE		
Sand and gravel	182	182
ULLIN LIMESTONE		
Ramp Creek Member		
Limestone, slightly cherty, gray, brownish gray, fine to medium, dense	13	195
Limestone, slightly cherty, brownish gray, little light gray, fine to medium, rather dense	5	200
Limestone, very cherty, brownish gray, fine, dense	5	205
Limestone, very cherty, brownish gray, little medium dark gray, light gray, fine, dense	35	240
Limestone, cherty, brownish gray, little light gray, very fine to fine, few dark grains and specks	20	260
Limestone, slightly cherty, light brownish gray, very fine to fine, few dark grains and specks	5	265
Limestone, cherty, brownish gray, little light gray, very fine to fine, few dark grains and specks	5	270
Limestone, drab gray, very fine to fine, rather dense	5	275
Limestone, slightly cherty, drab gray, little light gray, very fine to fine, dense	5	280
Same, but cherty in part, with black shale partings	26	306
Limestone, very cherty, silty, brownish gray, dense	4	310
Limestone, cherty in part, drab gray, light gray, very fine to fine, with streaks of siltstone, calcareous, very dark gray	10	320
Limestone, very cherty, silty, brownish gray, light gray, very fine to fine, some very silty, dark gray	20	340
Limestone, cherty, brownish gray, some light gray, very fine to fine	20	360
Same, but very cherty, in part silty, with dark, very silty streaks	10	370
Limestone, cherty, silty, brownish gray, little light gray, very fine, in part very silty, medium dark brownish gray, some very silty, very dark gray streaks	15	385
Same, but more cherty	10	395
Limestone, cherty to very cherty, silty, medium dark brownish gray, very fine, dense	5	400
Limestone, cherty to very cherty, silty, in part slightly dolomitic, brownish gray; some light gray, very fine; some very silty, dark brownish gray; in part with siltstone partings, calcareous, very dark gray	115	515

	Thickness (feet)	Bottom (feet)
Ramp Creek Member, continued		
Limestone, very cherty, silty, slightly dolomitic, brownish gray, light gray; in part medium dark brownish gray, very fine; in part very silty, dark brownish gray; few shaly partings	23	538
Limestone, very cherty, silty, slightly dolomitic, brownish gray, light gray, very fine; some shale, very dark gray	20	558
Measured Ramp Creek Member	376	
FORT PAYNE FORMATION		
Limestone, very cherty, very silty, medium dark brownish gray, some light gray, very fine, dense	12	570
Limestone, very cherty, silty, brownish gray, light gray, very fine; some very silty, dark brownish gray, very fine; very little shale, dark gray; chert is bluish gray to dark gray	10	580
Limestone, cherty to very cherty, silty to very silty, medium dark to dark brownish gray, very fine	25	605
Limestone, very cherty, very silty, dark brownish gray, very fine	23	628
Total Fort Payne Formation	70	
SPRINGVILLE SHALE		
Siltstone, dark gray, very fine, hard, pyritic	2	630
Siltstone, gray, very fine, hard	8	638
Siltstone, slightly calcareous, greenish gray, very fine, hard	8	646
Shale, dark greenish gray, dark gray	4	650
Shale, slightly calcareous, dark gray	1	651
Total Springville Shale	23	
NEW ALBANY SHALE		
Shale, black, brown streak, pyritic to slightly pyritic	29	680

Samples studied to depth of 1260 not recorded here.

Well 2.–Mid-Continent Oil Company No. 1-A Roscoe Herren, NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 12, T. 14 S., R. 1 E., Pulaski County, Illinois. Sample set 25875. Study by Jerry A. Lineback.

	Thickness (feet)	Bottom (feet)
No samples	225	225
SALEM LIMESTONE		
Limestone, coarse-grained, fossiliferous, crinoid-bryozoan, light brownish gray	15	240
Limestone, siliceous, cherty, fine to coarse, medium brownish gray	10	250
Limestone, coarse, fossil hash, cherty, medium brownish gray	30	280
Limestone, fine, light brownish gray	10	290

	Thickness (feet)	Bottom (feet)
SALEM LIMESTONE, continued		
Limestone, coarse, fossil hash, medium brownish gray	20	310
Limestone, cherty, fine to coarse, medium to dark brownish gray	35	345
Limestone, coarse, fossil hash, medium brownish gray	5	350
Limestone, cherty, coarse to fine, medium brownish gray	10	360
Limestone, coarse, fossil hash, medium brownish gray	20	380
Limestone, coarse, fossiliferous, crinoid-broyzoan, very light brownish gray	10	390
Limestone, medium granular, medium brownish gray	10	400
Limestone, coarse, fossiliferous, crinoids, somewhat oolitic, light brownish gray	20	420
Limestone, cherty, coarse to fine, medium brownish gray	10	430
Limestone, cherty, coarse, fossiliferous, medium brownish gray	10	440
Limestone, coarse, fossiliferous, bryozoans, light brownish gray	10	450
Limestone, fine, medium brownish gray	10	460
Limestone, cherty, coarse, fossiliferous, bryozoans-crinoids, light brownish gray	40	500
Limestone, cherty, coarse, fossiliferous, medium brownish gray	10	510
Measured Salem Limestone	275	
ULLIN LIMESTONE		
Harrodsburg Member		
Limestone, coarse, fossiliferous, bryozoan-crinoid, very little chert, light brownish gray	90	600
Ramp Creek Member		
Limestone, fine, medium brownish gray	10	610
Limestone, coarse, fossiliferous, granular, little chert, light brownish gray	70	680
Limestone, sucrosic, medium brownish gray	10	690
Limestone, granular, cherty, light to medium brownish gray	30	720
Limestone, coarse, fossiliferous, granular, cherty, light brownish gray	120	840
Limestone, fine to coarse, cherty, light to dark brownish gray	20	860
Limestone, coarse, fossiliferous, bryozoans, cherty, medium brownish gray	60	920
Limestone, fine, granular, siliceous, cherty. medium brownish gray, hard	130	1050
Limestone, fine, cherty, siliceous, medium to dark brownish gray	40	1090
Total Ramp Creek Member	490	
Total Ullin Limestone	580	

	Thickness (feet)	Bottom
FORT PAYNE FORMATION		
Limestone, cherty, very siliceous, somewhat silty and argillaceous, fine to very fine, dark brownish gray	110	1200
SPRINGVILLE SHALE		
Shale, silty, glauconitic, greenish gray	47	1247
CHOUTEAU LIMESTONE		
Limestone, light brownish gray, very fine to fine	4	1251
NEW ALBANY SHALE		
Shale, pyritic, dark brownish black	20	1271

Remainder of well not studied.

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